



A Balanced Diet for Lake Erie

Reducing Phosphorus Loadings and Harmful Algal Blooms

A Report of the Lake Erie Ecosystem Priority
February 2014

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Signed this 12th day of February, 2014, pursuant to Article 7 of the Great Lakes Water Quality Protocol of 2012, which gives the International Joint Commission the responsibility to provide advice and recommendations to the United States and Canadian governments on matters covered on the Annexes to the Agreement. This report addresses the challenge of nutrient pollution in Lake Erie.

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Foreword

The problem of excess nutrients in Lake Erie and resulting algal blooms has challenged scientists and troubled the public for more than 50 years. Stirred by public concern, governments responded with vigor to the problem in the 1960s and 1970s, resulting in measurable reductions in phosphorus inputs and a steep reduction in algal blooms. By the mid-1980s, the rapid recovery of Lake Erie was a globally-known success story.

However, Lake Erie is once again severely threatened. It is the shallowest of the Great Lakes, the warmest and the most susceptible to eutrophication and the effects of climate change. The recent accelerating decline of this lake, manifested as impaired water quality, massive, summer-long algal blooms, hypoxia and fish kills, has focused binational attention on the need for urgent actions to reduce external inputs of phosphorus. While Lake Erie's health suffers from multiple stressors, the rising proportion of dissolved reactive phosphorus is seen as the primary cause of this decline.

The return of severe Lake Erie algal blooms in the 2000s has again galvanized public concern and a governmental response. The worst algal bloom ever experienced on the lake occurred in 2011, prompting the International Joint Commission (IJC) to make binational investigation into the science and opportunities for action by governments to reduce algal bloom-causing pollution a priority.

The IJC recognizes and applauds the commitment of the United States and Canadian governments to restoring the lake's health. The United States Great Lakes Restoration Initiative is providing substantial funding to Lake Erie Basin restoration. The Canadian Great Lakes Nutrient Initiative is also contributing substantially to understanding the sources of excess nutrients and measures to reduce them. However, in carrying out the Lake Erie Ecosystem Priority, the IJC finds that more needs to be done.

The IJC offers its analysis and recommendations in this report in a spirit of cooperation, recognizing that today's challenges to Lake Erie's health are formidable and require the leadership and guidance of the United States and Canadian governments and collaboration by all sectors of society to again make the recovery of Lake Erie a globally-known success story.

Acknowledgements

This report is the product of a binational cooperative effort that involved more than 60 scientists, engineers, planners and technical experts in Canada and the United States. The IJC expresses its sincere appreciation to these individuals for their contributions to the planning, applied research and analysis that went into the preparation of this report. Their collaborative efforts have produced findings and recommendations that will enable the governments of Canada and the United States to more effectively address the challenges facing Lake Erie and the millions of citizens who depend on and enjoy its waters.

The current Commission would like to acknowledge and recognize the role of former Canadian Commissioners Lyall Knott, Pierre Trepanier and Joe Comuzzi (Chair) in establishing the study of Lake Erie as a Commission priority in 2012.

The IJC also acknowledges and thanks the many members of the public who participated in the outreach events in 2012 and 2013 and who provided valuable comments on Lake Erie's challenges and possible actions to address those challenges.

A detailed list of contributors to this report is provided in Appendix I.

We note, however, that the findings and recommendations in this report are solely the responsibility of the IJC.

*This report is dedicated to the memory of Dave Dolan (1949-2013) of the University of Wisconsin, with thanks for a lifetime of work improving our understanding of the Great Lakes. Dave contributed significantly to the **Taking Action on Lake Erie** scientific work group.*



2011 Algal Bloom, Lake Erie, Western Basin

Executive Summary

In 2011, Lake Erie experienced its largest algal bloom in history. In 2012, the International Joint Commission (IJC) established the **Lake Erie Ecosystem Priority (LEEP)** in response to a growing challenge: lake-wide changes in Lake Erie related to problems of phosphorus enrichment from both rural and urban sources, compounded by the influence of climate change and aquatic invasive species. These changes have resulted in impaired water quality, with impacts on ecosystem health, drinking water supplies, fisheries, recreation and tourism, and property values. This report presents the IJC's key findings and recommendations from the LEEP study.

The IJC is an independent binational organization created by Canada and the United States under the *Boundary Waters Treaty of 1909*. Under the Treaty, the two countries cooperate to prevent and resolve disputes relating to the use and quality of the many lakes and rivers along their shared border. The Great Lakes Water Quality Agreement (the Agreement) assigns the IJC a role in assessing progress, engaging the public and providing scientific advice to help the two countries restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes.

Background

The smallest and shallowest of the five Great Lakes, Lake Erie has long experienced changes as a result of human activities and natural forces. With 11.6 million people living in its basin, and a watershed dominated

by big cities and sprawling farmland with little forest cover, Lake Erie is severely impacted by human activities.

In the decades leading up to the 1970s, loadings of nutrients, particularly phosphorus from municipal sewage treatment plants and other anthropogenic sources, visibly degraded Lake Erie. This excessive nutrient enrichment, known as eutrophication, resulted in severe algal fouling of the lake, which in turn created aesthetic, taste and odor problems, reduced available oxygen and led to fish die-offs. Great Lakes eutrophication prompted the governments of Canada and the United States to sign the Agreement in 1972, establishing a binational commitment to reduce nutrient loadings and clean up the lakes.

Following the signing, governments on both sides of the international border made significant investments to upgrade and expand municipal sewage treatment plants. In addition, governments took action to reduce phosphorus concentrations in household detergents. By the mid-1980s, Lake Erie phosphorus loadings were reduced by more than half from 1970s levels, and many of the problems associated with eutrophication were reduced or eliminated, confirming that reducing phosphorus loadings led to improved water quality. Lake Erie's recovery was a globally-recognized success story.

However, by the early 2000s, problems with excess nutrient enrichment appeared again in Lake Erie, and have since continued to worsen. In recent years, the problem of harmful and nuisance algal blooms has be-

come widespread. In 2011, heavy spring rains flushed a large amount of phosphorus into western Lake Erie. This was soon followed by warm temperatures, creating a mass of algae that extended more than 5,000 km² (about 1,930 mi²), three times larger than the next largest bloom previously recorded.

Although eutrophication is again a serious threat to Lake Erie water quality, the sources and remedies are different from those of the 1960s and 1970s. While sewage plants still contribute some phosphorus to Lake Erie, diffuse runoff from rural and urban lands is a leading factor in eutrophication. **Of particular concern is runoff of dissolved reactive phosphorus, the portion of total phosphorus that is most readily available to support algae growth and thus a primary cause of renewed algal blooms.** Addressing runoff requires strategies tailored to particular land uses, rather than controls on sewage plants alone.

The LEEP Study

The core objective of LEEP is to provide advice to federal, state, provincial and local governments in their development of policy and management practices to help restore the lake's ecosystem by reducing nutrient loads and resulting harmful algal blooms.

To reach this objective, the IJC established study teams of independent experts, who worked to develop a better scientific understanding of the causes and controls of phosphorus loading into Lake Erie. The LEEP work plan focused on *scientific* priorities, though it included *socio-economic* and *regulatory* themes as part of a comprehensive approach. Each theme was addressed by a series of binational working groups led by various IJC advisory boards and councils or by IJC staff.

Engaging the public was an important component of the LEEP project from the start. More than 400 individuals and organizations participated in roundtables, open houses and public meetings hosted by the IJC in communities across the Lake Erie Basin in both Canada and the United States in 2012 and 2013. In

addition, a draft of the report was made available for public review and comment. The more than 130 comments provided by lakeside residents, anglers, boaters, farmers and other concerned residents and organizations helped strengthen the analysis and recommendations in the LEEP report.

Phosphorus Loading to Lake Erie

Phosphorus is the key nutrient limiting the amount of phytoplankton and attached algae in Lake Erie.

The primary sources of phosphorus loadings to Lake Erie in the decades leading up to the 1972 Agreement were municipal sewage plants. Today, however, external phosphorus loads occur largely as runoff from diffuse land uses such as fertilized farm fields, lawns and impervious surfaces including streets and parking lots.

Of the 2011 loadings, it is estimated that more than one-half came from tributaries into Lake Erie that are monitored, such as in larger agricultural areas and rural communities. Unmonitored areas, typically coastal communities and smaller agricultural areas adjacent to shorelines, and direct point sources were estimated to each account for about 16%, while Lake Huron and atmospheric sources each accounted for between 4-6% of external loadings.

Agricultural operations are a major source of phosphorus loadings into Lake Erie. These loadings result primarily from fertilizer application and manure. The bulk of this input occurs during spring snowmelt and heavy rainstorms, when significant amounts of phosphorus can be transported by runoff water.

Phosphorus from urban areas is associated with construction activities, stormwater runoff, combined sewer overflow discharges, lawn and garden activities, leaves from deciduous trees and pet waste. Pinpointing exact amounts of phosphorus loadings from the multitude of urban land uses is often difficult.

The atmosphere is another source of phosphorus loading. Atmospheric deposition represented an

estimated 6% of the total external load to Lake Erie in 2011. Phosphorus can find its way from the airshed into lake ecosystems through inputs to the watershed from rain or snowfall and by wind-transported particles.

Data-driven models show the existence of “hot spots” – locations in sub-basins within the major watersheds – that contribute a disproportionate share of the total amount of dissolved reactive phosphorus entering Lake Erie. The single largest source of dissolved reactive phosphorus that generates harmful algal blooms in the western basin of Lake Erie is the Maumee River.

A Lake Experiencing Profound Changes

Lake Erie continues to experience serious changes as a result of phosphorus loading, compounded by the growing influence of climate change. Precipitation patterns in the Lake Erie Basin under climate change are characterized by less frequent but more intense storms. Such intense events lead to higher nutrient runoff from agricultural and urban lands, and increased overall nutrient loads to Lake Erie. Depending on the timing of runoff, future nutrient loading, coupled with warmer water temperatures, could lead to increased severity and frequency of algal blooms.

Algal Blooms

Some species of algae and cyanobacteria (‘blue-green algae’) in Lake Erie can constitute harmful and nuisance algal blooms. Free-floating mats of cyanobacteria *Microcystis* and *Anabaena* predominate in the lake’s western basin and have the potential to produce toxins that pose a significant risk to fish, wildlife and human health. Some areas of the western basin also are affected by dense bottom mats of *Lyngbya*, which is a non-toxic but odorous cyanobacteria that has been reported in the Maumee Basin and other areas. In the eastern basin, large shoreline blooms of the attached filamentous green algae *Cladophora* foul recreational beaches, clog municipal and industrial water intakes, impair water quality and pose potential microbial health risks to wildlife, household pets and humans.

Hypoxia

Hypoxia refers to a condition where the dissolved oxygen content of water is reduced to very low levels. This can occur during the summer months in deeper lake basins such as the central basin of Lake Erie, where the water column stratifies in layers and the warmer oxygenated waters at the surface are separated from the colder, denser bottom water. High external nutrient inputs stimulate the production of excessive organic material (algae and other organisms) in the sunlit surface layers, and the subsequent decay of this material in the bottom waters rapidly depletes the supply of oxygen, creating “dead zones,” where dissolved oxygen levels are so low that fish and other aquatic life cannot survive. Hypoxic conditions also lead to the release of phosphorus from sediments, known as ‘internal loading,’ which also may contribute to the development of algal blooms.

Climate change could exacerbate the magnitude, duration and frequency of hypoxia in Lake Erie. Warmer future conditions are expected to facilitate an earlier and longer period of stratification (or layering) during summers, causing algal growth and hypoxic conditions to begin sooner and persist over an extended time period.

Fish

Lake Erie fisheries have important ecological, recreational and commercial value. Each species of fish has preferred food choices and temperature ranges, and all fish depend upon adequate dissolved oxygen.

The decomposition process of algal blooms can significantly reduce dissolved oxygen supplies, undermining native fish populations. When algae die, the decomposition process uses much of the dissolved oxygen in the bottom waters. A changing climate – warmer temperatures, less ice cover and increased frequency of intense precipitation events – could exacerbate algal blooms, reduce water clarity and exacerbate future hypoxia.

Over the longer term, phosphorus loading together with future climatic conditions could alter Lake Erie's rich and diverse fish community. Cold-water species and species sensitive to low oxygen and reduced water clarity would be expected to decline, while species more tolerant to warm water likely would thrive.

Human Health and Socio-economic Conditions

Individuals swimming, waterskiing, or boating in harmful algal blooms can be exposed to toxins. Although the likelihood of people being seriously affected by a bloom is low, minor skin irritation can occur with contact. As well, gastrointestinal discomfort and, in very rare but severe cases, acute liver failure can occur if water from a bloom is ingested. In the Great Lakes basin, only Lake Erie has had documented cases of human illness and animal (dog) deaths related to harmful algal blooms.

Public concerns about the impact of harmful algal blooms on drinking water in Lake Erie were heightened in the summer of 2013 when residents in Carroll Township, Ohio, were advised not to drink water from their local treatment plant due to high levels of microcystin - the first time a toxin associated with algae led to a plant shutdown in the state. In cases where harmful algal blooms appear, municipal water treatment facilities drawing water supplies from Lake Erie may need to carry out additional monitoring and treatment before the water is safe for human consumption.

Limited data constrain efforts to estimate the economic effects of Lake Erie algal blooms throughout the entire lake basin. Using Ohio data as a proxy for the broader Lake Erie Basin, the LEEP study identified important economic costs associated with effects on property values, regional tourism, beach tourism and recreational and commercial fishing.

Regulation and Policy

The IJC reviewed nutrient management statutes and programs among all eight Great Lakes states, Ontario and Quebec. Related recommendations were developed for the LEEP report, based in part on the most effective initiatives identified.

Improving the Health of Lake Erie: Opportunities for Action

New Loading Targets

The LEEP study developed response curves to predict levels of algal blooms and hypoxia as a function of phosphorus loading. These load-response curves, in turn, were used to identify new loading targets, as part of a comprehensive management plan to address these issues in Lake Erie.

The LEEP study concluded that to reduce algal blooms and areas of hypoxia significantly requires substantial reductions in phosphorus loads below current levels, and that the focus should be on reducing dissolved reactive phosphorus loads. Furthermore, in setting future targets, it will be important to recognize that harmful algal blooms and hypoxia targets likely will require separate considerations – solving one problem will not necessarily solve the other. Greater reductions in dissolved reactive phosphorus will be needed to address the hypoxia problem.

Best Management Practices¹:

The LEEP study involved a comprehensive review of more than 240 sources on the implementation and effectiveness of *best management practices* (BMPs) that could be considered for implementation within the Lake Erie Basin to reduce phosphorus loads. BMPs cover a range of proven, practical methods, techniques and other actions that allow individuals and organizations to prevent or reduce the risks of water pollution resulting from their activities.

¹ In Canada, best management practices typically are referred to as beneficial management practices.

The control of phosphorus in agricultural operations must focus on changes in agricultural practices that have been implemented in recent decades, such as increased prevalence of fall application of nutrients, applying two years' worth of fertilizer in a single application, and broadcast application. The goal is to increase the efficiency of phosphorus use at the farm scale. Promising approaches include improvements in the management of soil, manure, and mineral fertilizer, and agricultural and conservation practices that balance inputs and outputs of phosphorus within watersheds across the Lake Erie Basin. Extreme weather events can confound the effectiveness of agricultural BMPs.

Within urban areas, there are many diffuse sources of phosphorus. Therefore, BMPs will need to be highly varied and targeted for implementation in a wide range of urban activities.

Data and Knowledge Gaps

Accurately monitoring phosphorus loadings and identifying the most important sources allows for effective priority-setting of actions to restore the health of Lake Erie. The LEEP study identified several gaps with respect to monitoring of phosphorus loadings and their effects on the ecology of Lake Erie. These gaps include:

- an uneven distribution of tributary monitoring across the Lake Erie Basin;
- an absence of continuous monitoring near the mouth of the Detroit River;
- limited monitoring of the lake's nearshore zone; and,
- routine monitoring of critical wet weather events – an issue of increasing importance under climate change.

Knowledge research gaps include:

- how different physical, chemical, and biological factors interact to create the conditions that can trigger harmful and nuisance algal blooms;

- how different fish communities of the lake may respond under the warming trends and altered precipitation patterns associated with continued climate change; and,
- how much various BMPs actually reduce phosphorus loading, and how much they cost.

In addition, there is a need for timely and more comprehensive economic data that would allow for a better understanding of the economic impacts of algal blooms across the Lake Erie Basin.

Recommendations

Responsibility for the development and implementation of plans, programs, policies and related activities to address Lake Erie water quality rests with the governments of the United States and Canada and Ontario and the Lake Erie Basin states (Ohio, Michigan, Indiana, Pennsylvania and New York). The IJC serves in an advisory role to the governments, and offers its recommendations in a spirit of cooperation.

The IJC believes that current knowledge is sufficient to justify immediate additional efforts to reduce external loading of nutrients to Lake Erie. Phosphorus, especially the bioavailable dissolved reactive fraction, is a primary concern. Efforts must deal with both agriculture and urban sources. The highest priority for remedial action should be the Maumee River watershed.

The participation of the province of Ontario and Lake Erie Basin states is essential to realizing improved Lake Erie health. Due to their location around the lake and land use, some states have deeper phosphorus reductions to make than others. For example, while Lake Erie's western and central basins require urgent targeted phosphorus reductions, the states of Pennsylvania and New York State contribute phosphorus loads only to the eastern basin. Efforts to reduce phosphorous inputs into the eastern basin will have little impact on algal bloom and hypoxic conditions occurring upstream. However, reduced phosphorus

inputs into the eastern basin will benefit the local environment as well as Lake Ontario, which receives 80% of its flow from Lake Erie.

Based on the LEEP study's analysis and key findings, the IJC recommends the following actions:

Setting Phosphorus Reduction Targets

1. The Governments of the United States and Canada should adopt new targets for maximum acceptable phosphorus loadings in Lake Erie:

- to reduce the frequency and severity of harmful algal blooms in the western Lake Erie Basin to an acceptable level (None/Mild blooms), the total phosphorus load target for the Maumee River for the spring (March-June) period should be established as 800 metric tonnes (MT), a 37% reduction from the 2007-2012 average; for dissolved reactive phosphorus, the target for the spring period should be 150 MT, a 41% decrease from the 2007-2012 average; extended over the course of a full year, the total phosphorus target should be 1,600 MT, a 39% decrease from the 2007-2012 average;
- when the rest of the watersheds in the western Lake Erie Basin are included, the total phosphorus load target for the spring should be 1,600 MT and the dissolved reactive phosphorus target should be 300 MT; extended over the course of a full year, the total phosphorus target should be 3,200 MT;
- to decrease the central Lake Erie Basin hypoxic area by 50% to about 2,000 km² (772 mi²) and 10 hypoxic days a year, the target total phosphorus load for the western basin and central basin should be 4,300 MT, a 46% reduction from the 2003-2011 observed average load and 56% below the current target;
- when expressed as annual dissolved reactive phosphorus load, the target for achieving the same hypoxic area (2,000 km²) and number of hypoxic days (10) in the central Lake Erie Basin should be 550 MT. This new level represents a 78% reduction from the 2005-2011 average dissolved reactive phosphorus load; and,

- total phosphorus and dissolved reactive phosphorus targets should be phased in over a nine-year period (2014-2022) by setting transitional targets on a three-year basis to coincide with the triennial cycle and assessment of progress outlined in the 2012 Agreement.

2. To establish and implement new targets of phosphorus loadings:

- the governments of the United States and Canada should develop domestic action plans including both regulatory and non-regulatory measures to reduce nutrient pollution of Lake Erie sooner than the 2018 goal set in the 2012 Agreement;
- the governments of Michigan, New York, Ohio, Pennsylvania and Ontario should apply a public trust framework consisting of a set of important common law legal principles shared by both countries, as an added measure of protection for Lake Erie water quality; governments should apply this framework as an added decision-making tool in policies, permitting and other proceedings; and,
- the governments of Michigan and Ohio should, under the *United States Clean Water Act*, list the waters of the western basin of Lake Erie as impaired because of nutrient pollution; this would trigger the development of a tri-state phosphorus total maximum daily load (TMDL) involving those states and Indiana, with U.S. Environmental Protection Agency oversight.

Reducing Phosphorus Loading into Lake Erie from Agricultural Sources and Septic Systems

3. The Governments of the United States, Canada, Ontario, Michigan, Indiana, Ohio, Pennsylvania and New York should immediately expand the focus of existing and planned incentive-based agri-environmental programs beyond particulate phosphorus to include an emphasis on best management practices that are most likely to reduce dissolved reactive phosphorus, such as reducing the amount of phosphorus applied to fields, slowing the movement of water to the field drainage system, and detaining flows at field drainage outlets.
4. Future phosphorus management efforts of the Governments of the United States, Canada, Ontario, Michigan, Indiana, Ohio, Pennsylvania and New York should focus on:
 - avoiding agricultural applications of phosphorus in autumn;
 - reducing the load delivered during the spring period (March 1 to June 30); and,
 - those sub-watersheds that are delivering the most phosphorus into the lake, including the Maumee River.
5. The Governments of the United States, Canada, Ontario, Michigan, Indiana, Ohio, Pennsylvania, New York and local agencies should increase the scale and intensity of agricultural best management practices programs that have been shown to reduce phosphorus runoff.
6. The Governments of the United States, Canada, Ontario, Michigan and Ohio should:
 - commit to the goal of a 10% increase by 2030 beyond current levels of coastal wetland areas in the western basin of Lake Erie to reduce nutrient pollution and promote biodiversity (an increase of about 1,053 ha or 2,600 acres);
 - allocate adequate funding to support this significant first step in coastal wetland restoration, in concert with non-governmental funders; and,
 - set a science-based goal for protection and restoration of wetlands inland from the Lake Erie coastal zone and develop appropriate strategies to meet the goal.
7. The Governments of the United States, Canada, Ontario, Michigan, Indiana, Ohio, Pennsylvania and New York should strengthen and increase the use of regulatory mechanisms of conservation farm planning to reduce nutrient loadings.
8. The Governments of the United States, Canada, Ontario, Michigan, Indiana, Ohio, Pennsylvania, and New York should accelerate 4Rs (Right source, Right rate, Right time and Right place) outreach/extension programs, and phase in mandatory certification standards for agrology advisors, retailers and applicators to ensure fertilizer is applied based on the 4Rs.
9. United States and Canadian federal policies should link the cost and availability of crop insurance purchases or premiums to farm conservation planning and implementation of nutrient management practices.
10. The Governments of Ontario, Michigan, Indiana, Ohio, Pennsylvania and New York should ban the application of manure, biosolids and commercial fertilizers containing phosphorus from agricultural operations on frozen ground or ground covered by snow for lands that drain to Lake Erie.
11. The Governments of Ontario and Michigan should:
 - enact legislation requiring inspection of septic systems at regular intervals, and at the time of property sale or land severance, to identify and assure upgrade/replacement of failing and potentially failing systems; and,
 - expand state/provincial and community education

initiatives promoting homeowner awareness of the need for septic system maintenance, including regular pumpout, and upgrade/replacement.

Reducing Phosphorus Loading into Lake Erie from Urban Sources

12. The Governments of the United States, Canada, Ontario, Indiana, Michigan, New York, Ohio and Pennsylvania should work with municipalities to promote and accelerate the use of green infrastructure (such as filter strips, rain gardens, bio-swales, and engineered wetlands) in urban stormwater management in the Lake Erie Basin by:

- providing funding, regulatory direction and technical support to municipalities and, where feasible and appropriate as an alternative to more expensive stormwater controls, authorize green infrastructure in United States municipal water discharge permits and Ontario environmental compliance approvals; and,
- encouraging the adoption of local ordinances/by-laws promoting green infrastructure.

13. The Governments of Ontario, Ohio and Pennsylvania should prohibit the sale and use of phosphorus fertilizers for lawn care, with the exception of the establishment of new lawns during the first growing season or in cases where soil testing indicates a need for phosphorus.

Strengthening Monitoring and Research in the Lake Erie Basin

14. The Governments of the United States and Canada should commit sustained funding to enhance and maintain monitoring networks in the Lake Erie Basin, focusing on:

- tributaries throughout the Lake Erie Basin, including key sub-basins and wet weather events to

capture seasonal differences from a wider range of basin tributaries;

- dissolved reactive phosphorus which, in addition to total phosphorus and other parameters, will need to be regularly monitored at all appropriate sites;
- establishment of water quality monitoring stations to quantify the nutrient dynamics from Lake Huron through St. Clair River and Lake St. Clair;
- establishment of a continuous, long-term water quality monitoring system at the outlet of the Detroit River that measures critical nutrient parameters; and,
- an evaluation of the cumulative effectiveness of urban and rural best management practices.

15. The Governments of the United States and Canada should support research to strengthen understanding of:

- the dynamics of harmful algal blooms through a comprehensive limnological approach to studying entire bloom communities;
- how open-lake disposal of dredged sediments from the Toledo navigational channel affects phosphorus loadings in Lake Erie;
- environmentally sustainable methods of sediment disposal;
- how various factors, such as the interaction of lake water with land-based runoff and tributary discharges, can be used to predict the conditions associated with nuisance blooms under current and future climate change scenarios;
- how Lake Erie's diverse and productive fish communities could respond under the warming trends and altered precipitation patterns associated with continued climate change; and,
- the economic effects of Lake Erie algal blooms throughout the entire lake basin.

16. The Governments of the United States and Canada and organizations involved in lake management should improve data management through greater coordination and sharing.



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Runoff of soil and fertilizer



Brenda Culler, Ohio DNR

Chapter 1 Introduction to the Lake Erie Ecosystem Priority Report

1.1 Purpose of the Report

This report presents the findings and recommendations of the **Lake Erie Ecosystem Priority** (LEEP), which the International Joint Commission (IJC) initiated in 2012 as part of its three-year priority cycle to provide advice to federal, state/provincial and local governments for developing policy and management approaches to address lake-wide challenges with respect to declining water quality, algal blooms, hypoxia and associated ecosystem, human health and economic impacts.

The IJC is an independent binational organization created by Canada and the United States under the *Boundary Waters Treaty of 1909*. Under the Treaty, the two countries cooperate to prevent and resolve disputes relating to the use and quality of the many lakes and rivers along their shared border. At the request of both governments, under the Great Lakes Water Quality Agreement² (the Agreement), the IJC also has a role in advising the two countries on restoration and maintenance of the chemical, physical, and biological integrity of the waters of the Great Lakes.

Intended Audiences

The LEEP report was prepared to provide advice to the governments of Canada and the United States regarding the protection and restoration of Lake Erie. The findings and recommendations of the report also will be of direct interest to a broad audience of agencies, water users, residents, organizations and decision-makers concerned about water quality and the future of Lake Erie.

The report represents a synthesis of extensive scientific analysis. Readers wanting more detailed information are encouraged to review the original scientific and technical papers prepared as part of the study.³

1.2 Background to the Report

The Great Lakes basin, from the headwaters of Lake Superior to the outlet of Lake Ontario, is home to more than 45 million people in Canada and the United States. The five Great Lakes, created 10,000 years ago at the end of the last period of continental glaciation, make up the largest surface freshwater system on Earth. These waters support food crop irrigation, electrical power generation and transportation of raw materials and finished goods. They maintain rich

² For more information on the Great Lakes Water Quality Agreement, see: www.binational.net or ijc.org

³ LEEP papers are available at: www.ijc.org/en/_leep/Technical_Documents

wetlands and fisheries. They provide bountiful sources of drinking water and recreational opportunities for millions of people.

Yet human use of the lakes has degraded water quality and ecosystems. As the smallest (measured by volume) and shallowest of the five Great Lakes, Lake Erie has long experienced changes as a result of human activities and natural forces.

In the decades leading up to the 1970s, loadings of nutrients, especially phosphorus from municipal sewage treatment plants and other runoff sources, visibly degraded the lake. This excessive nutrient enrichment – also known as eutrophication – resulted in severe algal fouling of the lakes, which in turn created aesthetic, taste and odor problems, and fish die-offs. Although eutrophication was apparent at many locations around the Great Lakes, it was particularly evident in Lake Erie. This eutrophication led the governments of Canada and the United States to sign the Agreement in 1972, most recently amended in 2012, establishing a binational commitment to clean up the lakes.

Following the signing of the Agreement more than 40 years ago, governments on both sides of the border made significant investments to upgrade and expand municipal sewage treatment plants. In addition, governments took action to reduce phosphorus concentrations in household detergents. By the mid-1980s, Lake Erie phosphorus loadings were reduced by more than half from 1970s levels, and many of the problems associated with eutrophication were reduced or eliminated (Lake Erie Nutrient Science Task Group, 2009).

By the early 2000s, however, problems with nutrient enrichment and oxygen depletion appeared again, and have since continued to worsen. In recent years, the problem of harmful and nuisance algal blooms⁴ has once again become widespread. In 2011, heavy rains in the spring flushed a large amount of phosphorus, including large proportions of dissolved reactive phosphorus (DRP) – the portion of total phospho-

rus that is most readily available to support algae growth – from agricultural runoff, into western Lake Erie. Warm temperatures soon followed, creating a mass of algae that extended for more than 5,000 km² (about 1,930 mi²). **The 2011 algal bloom was the largest in the lake's history, three times larger than the next largest bloom previously recorded. Trends in agricultural practices, such as fertilization application timing (proximity to storm events) and tillage practice (no-till), and meteorological conditions, including heavy spring rainfall and warm and quiescent summer weather, contributed to the bloom (Michalak et al., 2013).**

The problems of nutrient enrichment in Lake Erie are compounded by the influence of climate change on temperature and precipitation regimes and ecosystem changes caused by aquatic invasive species such as *dreissenid* mussels (Lake Erie Nutrient Science Task Group, 2009). As a result of these influences, Lake Erie has experienced a decline in water quality over the past decade, with impacts on ecosystem health, drinking water supplies, recreation and tourism, and property values.

⁴ Excessive and relatively rapid growth of algae. Blooms can occur naturally as the result of a change in water temperature and current or as a result of an excess of nutrients in the water.

Great Lakes Water Quality Agreement and the International Joint Commission

The Agreement is widely regarded as one of the world's most successful binational environmental agreements. Originally signed by Canada and the United States in 1972, the agreement has been revised four times, with each revision responding to evolving priorities:

- The original 1972 Agreement set general and specific water quality objectives and mandated programs to meet them. It gave priority to point source pollution from sewage treatment plants and industrial sources, as well as changes to allowable levels of phosphorus in household detergents. Point source pollution was dramatically reduced and many visible and noxious pollution problems were alleviated, including harmful algal blooms in Lake Erie.
- The 1978 version of the Agreement adopted an ecosystem approach (one which considers the interaction of air, land, water and living things, including humans) and called for a broad range of pollution-reduction programs, including virtual elimination of the input of persistent toxic substances.
- The Agreement was amended in 1983 to enhance efforts to reduce phosphorus inputs to the Great Lakes. Scientists from both countries worked together to set the target loads for each lake that would need to be met to achieve the water quality objectives of the Agreement. Detailed plans to reduce phosphorus loading to receiving waters were developed and adopted by each jurisdiction in the basin.
- A 1987 amendment called for programs to restore both the quality of open waters and beneficial water uses in 43 of the most contaminated local areas in the basin. Conditions have improved significantly in a number of these 'Areas of Concern,' though only five have been restored and removed from the list.
- The 2012 Agreement contains several new Annexes responding to current and emerging challenges, including aquatic invasive species, climate change, habitat and species, and groundwater. It also shifts greater emphasis back to nutrients by requiring the development of specific lake objectives for water quality including nutrients (specifying interim targets), and the development of programs to accomplish those objectives.

The IJC continues to play an important role under the Agreement. In addition to engaging and informing the public, it analyzes information provided by the governments, assesses the effectiveness of programs in both countries and reports on progress.



2011 Algal Bloom, Lake Erie, Western Basin

NASA

1.3 Establishment of the Lake Erie Ecosystem Priority

In 2012, recognizing the urgency and importance of Lake Erie's faltering health, and the potential cost of further delay, the IJC established the Lake Erie ecosystem as a priority area for binational study. The IJC has spent much of the past two years developing a better scientific understanding of the causes and controls of phosphorus in Lake Erie. This report presents the outcome of this work.

While the report focuses on phosphorus, the IJC recognizes that stressors other than nutrients also can adversely affect the water quality and ecology of Lake Erie. These stressors include erosion of shorelines and streambanks, chemical contaminants, wetland loss, and hydrologic alteration through dams.

LEEP is intended to complement several important initiatives to reduce nutrient loadings into the Great Lakes already underway at the federal, state, provincial and municipal levels. These initiatives include the binational Lake Erie Lakewide Action and Management Plan (LAMP) and its related publications (for example, LAMP, 2011), Environment Canada's Great Lakes Nutrient Initiative, the United States' Great Lakes Restoration Initiative (coordinated by the United States Environmental Protection Agency [USEPA]), and Ohio's Lake Erie Phosphorus Task Force.

1.4 Study Approach

Key Themes

The LEEP work plan primarily addressed science, and secondarily socio-economic and regulatory themes as part of a comprehensive approach. The themes were addressed by binational working groups led by the IJC's Great Lakes Science Advisory Board, Great Lakes Water Quality Board, Council of Great Lakes Research Managers, and IJC staff.

The science theme addressed five interrelated concerns regarding Lake Erie algae outbreaks:

- current external and internal phosphorus loading;
- effects of climate change on phosphorus loading, algal blooms, wetlands and fish;
- effectiveness of agricultural and urban best management practices (BMPs);
- management models and targets for phosphorus, harmful algal blooms (HABs) and hypoxia; and,
- adequacy of phosphorus monitoring programs within the Lake Erie Basin.

The Great Lakes Science Advisory Board was tasked with the first four of these issues. It convened a *Taking Action on Lake Erie* (TAcLE) work group, composed of advisory board members and experts in the field. The work group carried out extensive literature reviews, conducted independent analyses and modeling, and prepared papers summarizing the findings

⁶ International Joint Commission Retreat in Montreal, QC, Canada (Winter 2012)

and conclusions. The fifth science issue, the adequacy of phosphorus monitoring programs within the Lake Erie Basin, was addressed by the Council of Great Lakes Research Managers. Draft science papers were reviewed at an experts' workshop in February 2013, after which the report authors revised the papers and presented them to IJC staff.

Under the *socio-economic* theme, the study commissioned an expert paper on the economic impact of excessive algal blooms and the costs and benefits of solutions.

Finally, under the *regulatory* theme, IJC staff prepared a paper on the legislative and regulatory framework affecting sources of nutrients entering Lake Erie, including policies in place at the United States and Canadian federal levels and in the Great Lakes states and the province of Ontario.

Public Engagement

Throughout the LEEP process, the IJC made extensive efforts to inform and engage the public in both

the United States and Canada. Early on, this process included a roundtable in March 2012, held in Ann Arbor, MI and attended by more than 60 people. The presentations and discussions improved the IJC's understanding of the challenges facing Lake Erie and helped to frame the LEEP work plan.

In the summer of 2012, a series of eight public meetings was held to invite input. Comments provided by lakeside residents, anglers, boaters, and other concerned residents were important contributions to the analysis and recommendations in the draft LEEP report that was released in August 2013 for public review and comment.

In September and October of 2013, more than 400 people attended a second set of public meetings, which were held in: Detroit, MI; Milan, Oregon and Cleveland, OH; Port Stanley, Leamington and Walpole Island First Nation, ON; and as part of the Great Lakes Week conference in Milwaukee, WI. Comments also were invited online through the IJC's website.⁵ Commenters represented a wide range of interests. The LEEP report includes many improvements suggested by the public.

Key Concerns Expressed During the LEEP Public Engagement Activities

Of the more than 130 comments received, several key concerns were expressed by the public:

- the need to deal with uncertainty surrounding the contribution of the Detroit River (and the City of Detroit sewage treatment plant) to phosphorus loads in Lake Erie;
- the role of agriculture as a driver of the problem and as a solution, including both agronomic practices and CAFO (Concentrated/Confined Animal Feeding Operations) management;
- the need for additional regulatory tools to reduce phosphorus loading that complement existing incentive-based programming;
- the need for more research into development and adoption of suitable best management practices for the Lake Erie watershed;
- an emphasis on dissolved reactive phosphorus-specific best management practices, but not at the expense of particulate phosphorus and sediment-focused best management practices;
- the importance of drinking water considerations (partially a result of the *Microcystis* toxin found in the Carroll Township water plant);
- the adoption of a Total Maximum Daily Load program for Lake Erie in the United States and an equivalent program in Canada;
- the need for protection and restoration of natural land cover, including wetlands, to reduce and filter sediment and nutrient runoff; and,
- the need to address failing septic systems as a source of nutrients.

⁵All public comments received during the LEEP process are posted at http://www.ijc.org/en/_leep/Comments.

1.5 Organization of the Report

The balance of this report is organized into the following three chapters:

Chapter 2 summarizes the impacts of phosphorus loading, compounded by the influence of climate change and aquatic invasive species, on the Lake Erie ecosystem, human health and socio-economic conditions.

Chapter 3 reviews existing and possible initiatives to address the impacts on the Lake Erie ecosystem from phosphorus loading. It discusses modeling efforts to identify new phosphorus loading targets that could be established to reduce the loadings into Lake Erie, and identifies BMPs to reduce phosphorus runoff from agricultural operations and urban development. It also identifies important gaps in monitoring and research.

Chapter 4 presents the IJC's recommendations for addressing the challenges facing Lake Erie.

The Appendix includes acknowledgements, previous recommendations, references, a glossary, and a conversion table for comparing metric and United States customary units.



Less frequent, but more intense thunderstorms will lead to increased nutrient runoff.



A common non-structural BMP is reducing phosphorus loads from lawn fertilizers.

Chapter 2

Understanding the Changing Lake Erie Ecosystem

The science component of the **Lake Erie Ecosystem Priority** (LEEP) focused on improving understanding of how phosphorus loadings are affecting water quality in Lake Erie. Science investigations explored the issues of harmful algal blooms (HABs)⁶ in the lake's western basin and oxygen depletion or hypoxia in the central basin. The socio-economic and regulatory components considered the impacts of these changes on human health, boating, recreational fishing and other activities.

Chapter 2 presents the results of these efforts to better understand why and how Lake Erie is changing. The chapter:

- provides a brief overview of the physical and socio-economic context of Lake Erie;
- describes trends in phosphorus loading to the lake, as well as the contributions from various sources; and,
- describes the effects of phosphorus loading, compounded by the influence of climate change and aquatic invasive species, on water quality in Lake Erie and on human health and socio-economic conditions in the basin.

2.1 Overview of the Lake Erie Ecosystem

Lake Erie is the shallowest and the smallest of all the Great Lakes⁷, with a total surface area of 25,700 km² (about 9,900 mi²) and an average depth of only 19 m (62 ft) (LAMP, 2012; GLIN). The lake is naturally divided into three distinct basins with different average depths: the western basin (7.4 m or 24.1 ft); the central basin (18.5 m or 60.1 ft); and, the eastern basin (24.4 m or 79.3 ft) (GLFC, 2003; Lake Erie LAMP, 2011). As a result, the lake waters warm rapidly in the spring and summer, and can freeze over in winter.

On an annual basis, about 80% of Lake Erie's total inflow comes from the St. Clair River, which conveys flows from the upper lakes of Superior, Michigan and Huron through the Detroit River into the lake's shallow western basin. About 11% of the inflow is from rain and snow. The balance comes from tributaries, the largest of which is the Maumee River (LAMP, 2011). Other major tributaries are the Sandusky, Cuyahoga, Grand, Raisin, and Huron rivers. The Detroit River also conveys flows from tributaries discharged into Lake St. Clair, including the Thames River. Lake Erie drains into Lake Ontario via the Niagara River.

⁶ Harmful algal blooms (HABs) result from the proliferation of blue-green algae (including cyanobacteria) in environmentally stressed systems, where conditions favor opportunistic growth of one or more noxious species, which displace more benign ones. These blooms are considered harmful because excessive growth can harm ecosystems and produce poisons (or toxins) that can cause illness in humans, domestic pets and wildlife.

⁷ As measured by volume. Lake Ontario has a smaller surface area (about 19,000 km² or 7,340 mi²) but is much deeper than Lake Erie.

Lake Erie's shoreline of 1,402 km (871 mi) and land basin of 58,800 km² (about 22,700 mi²) include parts of Indiana, Michigan, Ohio, Pennsylvania, New York and Ontario (CCGLHHD, 1977). The Lake Erie Basin is the most densely populated of the five Great Lake basins, with 17 metropolitan areas with populations of more than 50,000 and a total population of 11.6 million (LAMP, 2011).

Key Lake Erie users include: domestic, municipal and industrial water users; shipping; coastal zone residents and commercial interests; Tribes, First Nations and Métis; agricultural interests; recreational boating and tourism; and sport and commercial fishing interests.

With its fertile soils, the Lake Erie Basin is intensively farmed, with about 63% of the lake's watershed used for agriculture (Figure 2-1). Land use along the shoreline is dominated by: residential uses (39% in Canada and 45% in the United States); agriculture (21 and 14%, respectively); and, commercial uses (10 and 12%, respectively) (Environment Canada and USEPA, 1995).

The shallowness of the lake and its warm temperatures makes it the most biologically productive of all the Great Lakes. It supports a species-rich and diverse fish community, with more than 130 species documented. In addition to their important ecological roles, several species also support large recreational and commercial fisheries. For example, walleye (*Sander vitreus*) supports the lake's most valued recreational fishery and yellow perch (*Perca flavescens*), walleye and several other species support large commercial fisheries.

2.2 Phosphorus Loading

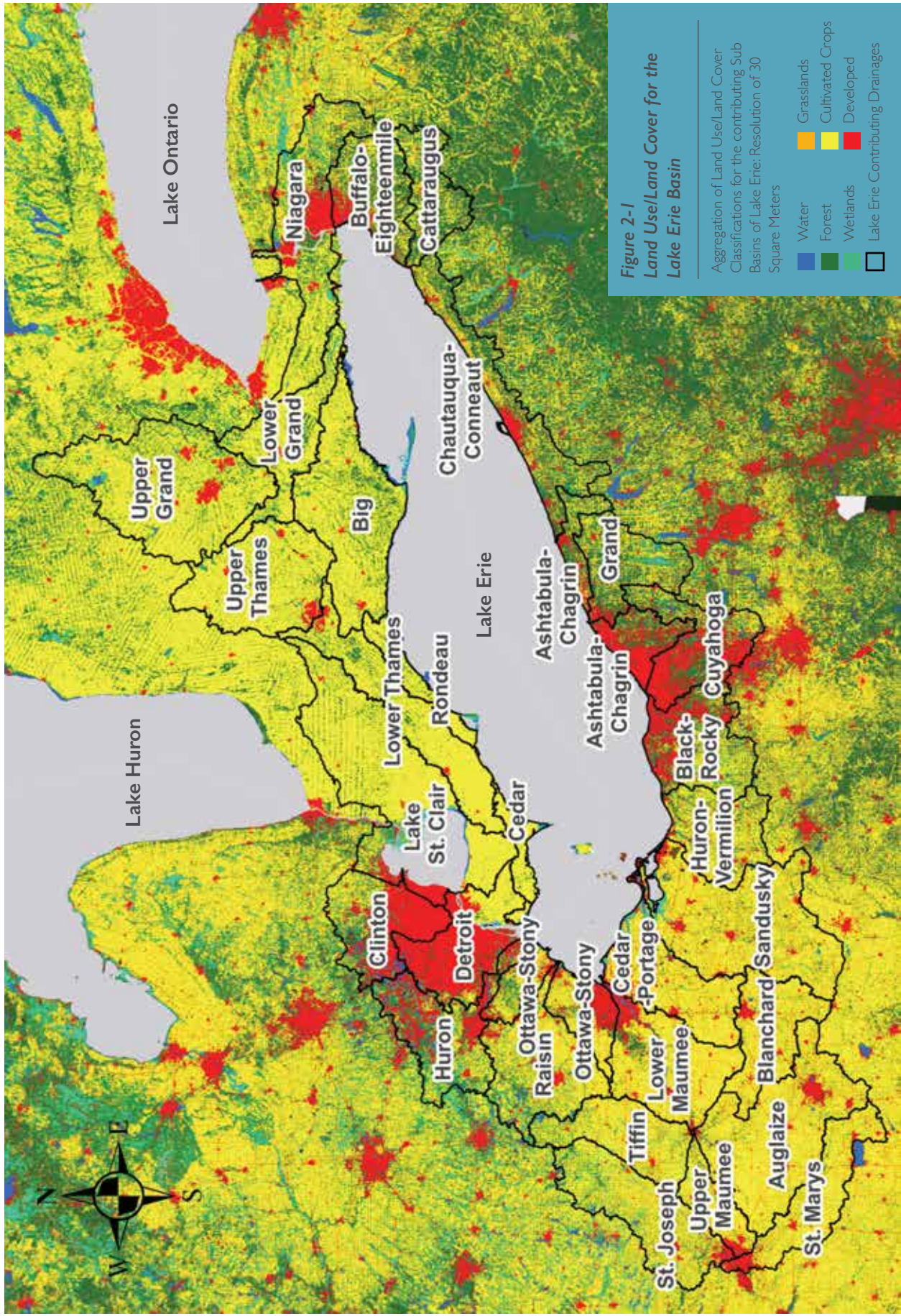
Phosphorus has long been recognized as the primary cause of nutrient enrichment (eutrophication) problems in most temperate zone lakes, including Lake Erie (Schindler 2012; Scavia *et al.*, 2014). Microscopic plants, the smallest forms of algae, comprise the base of the food web in any lake. Algae grow by converting available nutrients in the presence of sunlight to new plant material. The dominant types of nutrients

in Lake Erie are made up of nitrogen and phosphorus. **However, phosphorus is considered the limiting nutrient in the lake (that is, the nutrient that limits the growth of algae) because there is almost always sufficient nitrogen available for algal growth (Lake Erie Nutrient Science Task Group, 2009).**

Phosphorus is a chemical element that occurs both naturally in the environment and in many common commercial products. The major commercial application of phosphorus compounds is the production of fertilizers, used to replace the phosphorus that plants remove from the soil. Phosphorus is also an ingredient in many detergents, pesticides and other products.

To support the development of effective policy and management approaches to addressing lake-wide challenges in Lake Erie, LEEP sought to:

- provide the best available updated estimates of the total phosphorus (TP) load and bioavailable phosphorus (commonly referred to as DRP) for Lake Erie through to 2011, by tributary/watershed; and,
- evaluate the relative contributions from various sources to total loading.



Note: The map is based on harmonized Canadian Fundamental Drainage Areas (FDA) and the U.S. Watershed Boundary Dataset (WBD). The Canadian Units are 4-digit Sub Basins and the U.S. Units are 8-digit Sub Basins.

Source: IJC, modified from Great Lakes Aquatic Habitat Framework (GLAHF), University of Michigan.

2.2.1 Nutrient Limitation in Aquatic Ecosystems

Phosphorus and nitrogen, along with carbon and several other nutrients, including iron, manganese and zinc, are essential for algal growth. Nutrient limitation occurs when an essential nutrient is in short supply and algal growth is slowed or stopped, which often leads to changes in algal community composition and structure. Knowledge of which nutrients (and their forms) are primarily responsible for stimulating algal growth is important for devising solutions to issues of HABs and hypoxia associated with eutrophication. Different types of aquatic ecosystems tend to be limited by different nutrients. For example, algal growth in saltwater environments such as estuaries and coasts primarily is limited by nitrogen, while the open ocean generally is limited by either nitrogen or iron (Howarth and Marino, 2006). Rivers can be limited by either nitrogen or phosphorus, depending on river attributes such as stream size, flow rate, network complexity, and catchment land use and land cover.

Decades of nutrient inputs to watersheds from human sewage, livestock manure and commercial fertilizer typically result in lakes that are highly enriched in both nitrogen and phosphorus. For freshwater lakes across the temperate zone, the general view is that algal growth is controlled by phosphorus availability and that excessive loads of phosphorus lead to eutrophication (Schindler, 2012). Exceptions include some saline and montane lakes, where nitrogen can be limiting and prairie landscapes dominated by agriculture where phosphorus is replete (Baulch, 2013). Similarly, there is some evidence for nitrogen limitation or co-limitation, as well as other trace elements, with phosphorus in the context of mixed algal communities, near simultaneous limitation thresholds of nitrogen and phosphorus, and seasonal and spatial heterogeneity (DeBruyn et al., 2004; Lewis et al., 2011; Dolman et al., 2012).

In the western basin of Lake Erie, strong relationships have been observed between measurements of discharge and phosphorus loads from key tributaries and

the reoccurrence of HABs (Stumpf et al., 2012; Michalak et al., 2013) and between phosphorus loads and central basin hypoxia (Rucinski et al., 2014; Scavia et al., 2014). **Both bodies of research provide convincing evidence that the single most important solution for the restoration of Lake Erie water quality is the reduction of phosphorus inputs.**

Key Terms Used in the Report

1. *Total Phosphorus, Particulate Phosphorus and Dissolved Phosphorus*

- Total phosphorus (TP) is the sum of all fractions of phosphorus in a given quantity of water, including particulate and dissolved fractions.
- Particulate phosphorus (PP) refers to the fraction of phosphorus that is attached to suspended sediment and organic matter and dissolved phosphorus refers to the fraction that is dissolved in the water column. The dissolved fraction is generally referred to as soluble reactive phosphorus (SRP) or dissolved reactive phosphorus (DRP). This report uses DRP to reflect the more commonly used term in the Lake Erie watershed.
- Not all of the phosphorus entering a lake from its tributaries is readily available to support algal growth. Bioavailable phosphorus refers to the form of phosphorus that stimulates algal growth. Most of the phosphorus expressed as DRP is considered bioavailable (greater than ~90%); a much smaller portion of PP is described as bioavailable (less than ~30%).

2. *Point and Non-point Sources of Pollution*

- Point source pollution comes from specific locations in a river network or along the shoreline of a lake. Discharges from industrial activities and effluents from wastewater treatment plants are examples of point sources.
- Non-point source (NPS) pollution comes from many locations and origins distributed throughout a watershed as a result of land-based human activities such as agriculture, construction and forestry. Pollutants including sediments from soil and streambank loss, nutrients and bacteria from fertilizers and manures, pesticides and other chemical contaminants are transported by rainfall and snowmelt runoff over land and through groundwater systems before entering rivers and lakes. NPS pollution is also referred to as diffuse pollution.
- Atmospheric deposition is a source of NPS pollution.
- Pollution from built-up and urban regions, including residential areas, can be described as both point source and NPS depending on such factors as region size, density of buildings and people, and the extent and composition of green spaces and natural habitats.

3. *External and Internal Loading of Phosphorus*

- External loading refers to the quantity of phosphorus that enters a lake from external sources, including contributions from watersheds via river networks, direct discharges from human activities along lake shorelines, and atmospheric deposition.
- Internal loading refers to the quantity of phosphorus within in a lake that is derived from in-lake sources, primarily from profundal or lake-bottom sediments. Internal loading is facilitated by hypoxia (low oxygen levels) that periodically occurs near the sediment-water interface. Though all lakes have background levels of phosphorus, excessive nutrient loading means that the bulk of the phosphorus that comprises internal loading is originally from external sources.

Loadings vs. Concentrations

The amount of phosphorus in Lake Erie is generally expressed as *loadings* or *concentrations*:

- A **loading** is the mass of phosphorus entering the lake from one or more sources. It is expressed as the mass of phosphorus per given period of time (e.g., kg/day or metric tonnes/year). It typically is used to quantify inputs, such as from streams and rivers.
- A **concentration** is the mass of phosphorus in a given volume of water, generally expressed as milligrams or micrograms of phosphorus per litre. It is often used to characterize the trophic status of a lake or river.

For tributaries entering Lake Erie, loadings are calculated as the product of concentration (e.g., mg/L) and water discharge or flow rate (e.g., cubic feet per second [cfs] or liters per day [L/day]). Loadings and concentrations are not necessarily related. For example, during the spring freshet or snowmelt period, there tends to be large quantities of runoff and streamflow and high concentrations of phosphorus. Later in the summer, during the growing season, there can still be storms that generate large quantities of streamflow, but concentrations of phosphorus can be much lower. It is this combination of seasonality, water volume and phosphorus concentration that differentially impact receiving waters that range from the pelagic or open water zone to the nearshore zone and coastal embayments.

The algae issues in Lake Erie – including free floating *Microcystis* in the western basin, and attached *Cladophora* at various locations along the shoreline – occur primarily due to high concentrations of dissolved phosphorus coming from tributary discharges. Deep water hypoxia in the central basin is strongly influenced by phosphorus loads delivered from the west basin. Therefore, reducing phosphorus impacts on the lake must focus on both high concentrations and high load inputs, which primarily come from a few key tributaries including the Maumee River in northwest Ohio. Reducing loads from low concentration sources like the Detroit River may have only a modest influence on algal blooms in the western basin of the lake, though circulation patterns may transfer the influence of load reduction elsewhere, such as the central basin.

2.2.2 Trends in Phosphorus Loading into Lake Erie

External Loading into Lake Erie

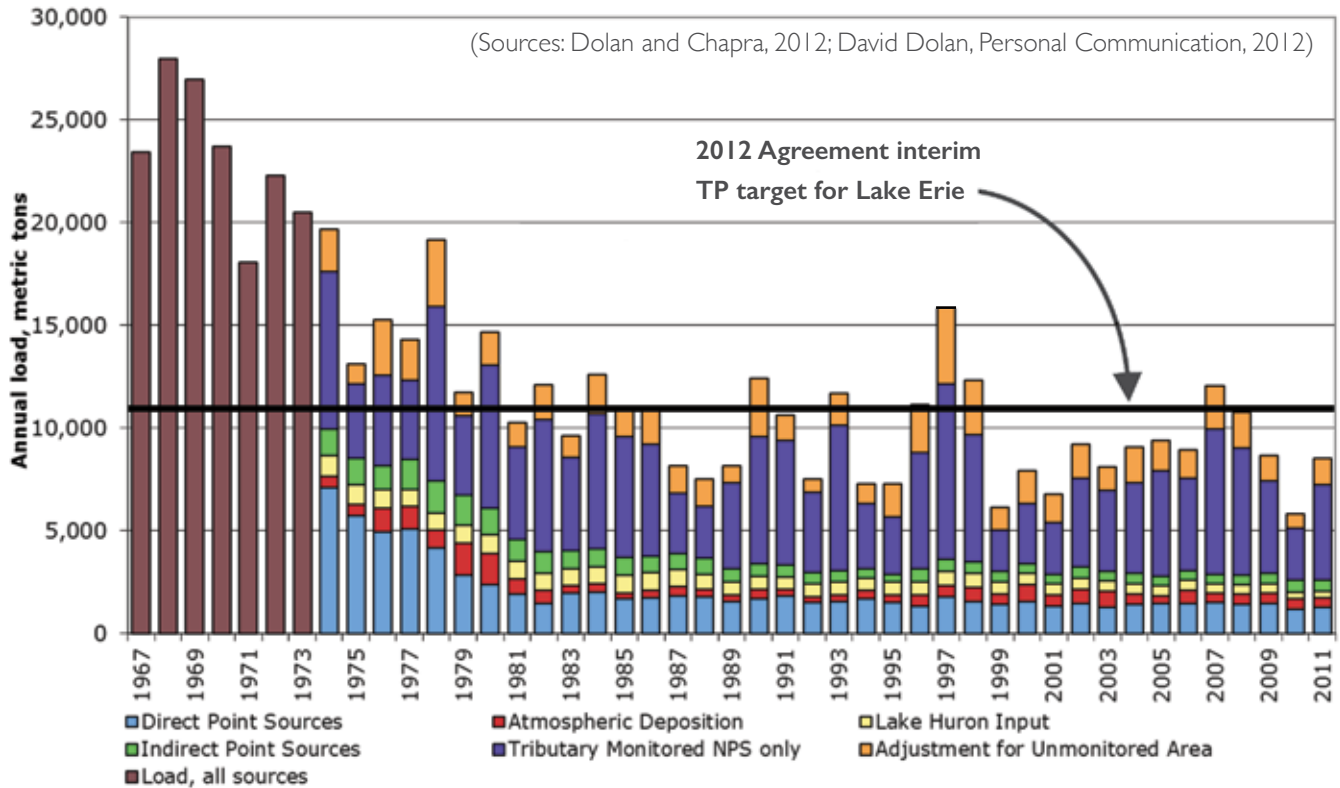
Researchers have updated TP loads for all of the Great Lakes, including from municipal and industrial point sources, monitored and estimated non-point sources, atmospheric deposition, and inter-lake transfers for 1994 to 2008 (Dolan and Chapra, 2012). LEEP updated these estimates for Lake Erie loads through 2011 using the same methods.

Figure 2-2 illustrates total external loadings of phosphorus into Lake Erie, from various sources, from

1967 to 2011. The study found that in most years, TP loadings into Lake Erie have been below the 11,000 metric tonnes (MT) a year target established under the Great Lakes Water Quality Agreement (the Agreement). Over the past 10 years, external loadings rose to a peak of nearly 12,000 MT a year in 2007, declined for three years and then again increased in 2011, to more than 8,500 MT.

The study concluded that the most dramatic reduction in loads into Lake Erie between the late 1960s and the early 1980s came from decreases in point sources of phosphorus, such that current loads are largely from non-point sources. Of the 2011 loadings, more than half came from tributaries into Lake Erie that are monitored, such as larger agricultural areas

Figure 2-2
Annual External Total Phosphorus Loads to Lake Erie (Metric Tonnes)



Note: This figure shows the annual external total phosphorus (TP) loads (in metric tonnes, MT) to Lake Erie for the years 1967 to 2011. Total loads were not differentiated for the period prior to 1974. The horizontal black line refers to the 2012 Great Lakes Water Quality Agreement interim annual TP load of 11,000 MT. NPS stands for non-point source.

and rural communities. Unmonitored areas (typically coastal communities and smaller agricultural areas adjacent to shorelines) and direct point sources each accounted for about 16%, while other sources each accounted for between 4 and 6% of external loadings. No long-term trends were identified over the period examined. Rather, annual variability in total external loading is driven largely by variability in loadings from the monitored tributaries.

Phosphorus loads to Lake Erie are not distributed equally across the basin. The western basin received 64% of the 2003-2011 average loads, while the central and eastern basins received 26 and 11%, respectively (Dolan and Chapra, 2012). Loads within each basin also vary among tributaries for both TP and DRP, with the largest contributions coming from the Maumee, Detroit, Sandusky, and Cuyahoga rivers.

In general, phosphorus concentrations in the open water decrease from west to east and from near-shore to offshore. The northern waters of the western basin are strongly influenced by flows from Lake Huron via the Detroit River, which tends to have comparatively low concentrations of phosphorus due to the large volume of water. Meanwhile, the lake's southern waters are influenced by the Maumee River and other Ohio watershed inputs, which have very high concentrations of phosphorus in a much smaller volume of water.

Differences in phosphorus loads across watersheds are affected by a wide variety of factors, including watershed size and drainage network topology, hydrological processes, surficial geology and soils, distribution and fragmentation of native vegetation,

settlement patterns and population density, industrial and agricultural activities, and the extent and effectiveness of nutrient management planning and water quality protection measures. Two of the largest watersheds that contribute nutrients to the western basin of Lake Erie are: the Maumee in the United States, which discharges directly into the western basin of Lake Erie; and, the Thames in Ontario, which discharges into Lake St. Clair, upstream of the Detroit River. Though their river lengths are similar (220 km [about 136 mi] for the Maumee and 275 km [about 167 mi] for the Thames), their watershed areas are different (16,500 km² [about 6,369 mi²] for the Maumee and 5,300 km² [about 2,046 mi²] for the Thames). The land use of both watersheds is dominated by agriculture. Both support livestock farming, particularly in their upper watersheds. However, the Maumee watershed is dominated by corn-soybean rotations, while the Thames is composed of corn-soybean rotations plus a broader array of commodities and cropping systems. Differences in land use zoning between the two jurisdictions, as well as differences in agricultural management, physiographic relief and soils, makes watershed-to-watershed comparisons of phosphorus concentrations and loads difficult to interpret.

Establishment of load targets for Lake Erie, or targets for any other aquatic system, is predicated on measurements of flow (or deposition) rates and nutrient concentrations from rivers throughout the watershed. Numerous water quality monitoring programs are in operation in the Lake Erie watershed, including Heidelberg University's National Center for Water Quality Research in Ohio, state agencies and the United States Geological Survey (USGS), the province of Ontario's Provincial Water Quality Monitoring Network, and Environment Canada's Great Lakes Nutrient Initiative, among others. These programs are focused on tributaries that discharge directly into Lake Erie, though it includes others that discharge into Lake St. Clair, such as the Thames and Sydenham rivers.

A critical influence on nutrient dynamics in Lake Erie is assumed to be the Detroit River. The river is thought to contribute 90% of the discharge and about 50% of the phosphorus to the western basin on a

mean annual basis. By the time the river discharges into the northwest corner of Lake Erie, it has integrated nutrient sources from the upper Great Lakes via the St. Clair River; tributaries of Lake St. Clair, including the Thames River in southwestern Ontario, and the cities of Windsor and Detroit (location of one of the largest wastewater treatment plants in North America). However, the only monitoring data available for the connecting river system between the upper Great Lakes and Lake Erie are from the northern section of the St. Clair River, just after water exits Lake Huron. At this point, the average annual (2005-2010) load of phosphorus is 326 MT (Dolan and Chapra, 2012). While no comparable monitoring data exist for the Detroit River outlet, research conducted in 2007 estimated that the annual phosphorus load from the river to Lake Erie was 3,500-4,300 MT, suggesting at least a 10-fold increase between Lake Huron and Lake Erie (Bruxer *et al.*, 2011). An important conclusion from this research is that future monitoring of the lower reaches of the Detroit River requires a series of monitoring stations to account for complexities associated with multiple channels and islands.

Agricultural Sources

Agricultural operations are the major source of non-point loadings of phosphorus into Lake Erie (Michalak *et al.*, 2013). These loadings can arise particularly from fertilizer application and manure. During spring snowmelt and heavy rainstorms, phosphorus is transported by runoff. Agricultural non-point sources of phosphorus have increased significantly in the last 15 years, especially the fraction of TP that is bioavailable (Baker, 2010).

Urban Sources

Phosphorus from urban areas is associated with discharges from wastewater treatment plants, construction activities, stormwater runoff, lawn and garden activities, leaves from deciduous trees and pet waste. Although urban non-point sources of phosphorus can be significant, discharges from urban areas often are closely associated with point sources. Over the last 40 years, discharges from most point sources have

declined significantly. However, wet weather overflows that bypass municipal wastewater treatment plants during and after heavy rainfall or snowmelt can discharge significant loadings of phosphorus.

Atmospheric Deposition

Atmospheric deposition to lakes contributed about 6% of the total external phosphorus load in 2011. Phosphorus can find its way from the airshed into lake ecosystems via inputs to the watershed from rain or snowfall (known as wet deposition) and wind transported particles (dry deposition) (Anderson

and Downing, 2006; Zhai *et al.*, 2009). Wet and dry nutrient loadings to aquatic ecosystems, particularly phosphorus, have increased over the years as a direct result of human activities (Herut *et al.*, 1999; Zhai *et al.*, 2009). Important potential sources of atmospheric deposition of phosphorus into Lake Erie include: microbial decomposition of sewage sludge, landfill and compost heaps; coal combustion; burning of biomass; dust from quarries, agricultural fields and unpaved roads; and automobile emissions.

Detroit Wastewater Treatment Plant

The Detroit wastewater treatment plant is one of the largest sewage plants in North America, serving more than three million people in 76 communities and treating an average of about 2.7 million m³ (710 million gallons U.S.) per day of wastewater. The plant discharges into the Rouge and Detroit rivers upstream of Lake Erie. Cleanup of the facility's discharges in the 1970s was one of the most important factors in the reversal of Lake Erie eutrophication.

In 1970, the facility began removing phosphorus from its effluent using pickle liquor and polymer to meet a 1 mg/L phosphorus standard for all major plants (about 3,800 m³ or 1 million gallons per day or greater). State policy changes affecting household laundry detergents also contributed to the cleanup. Michigan's 1977 phosphorus detergent rules restricted the phosphorus content of household laundry detergents to no greater than 0.5% by weight.

The combined result was a greater than 90% reduction in phosphorus concentration and loading from the treatment plant. Given the size of the Detroit plant, the improvement in the quality of Lake Erie's water was substantial.

Concerns about the current impact of the facility's discharge on western Lake Erie algal blooms were voiced by a number of parties at the IJC's LEEP public meetings in 2012. Similar concerns about phosphorus discharges from the plant and from combined sewage overflows (which result from major storms that force the bypass of untreated or partially treated sewage from the plant into the river) have resulted in more stringent pollution permit requirements. For example, the facility's most recent permit issued by the Michigan Department of Environmental Quality requires a reduction in monthly average TP concentrations in effluent from 1 mg/l to 0.7 mg/l beginning in January 2015.

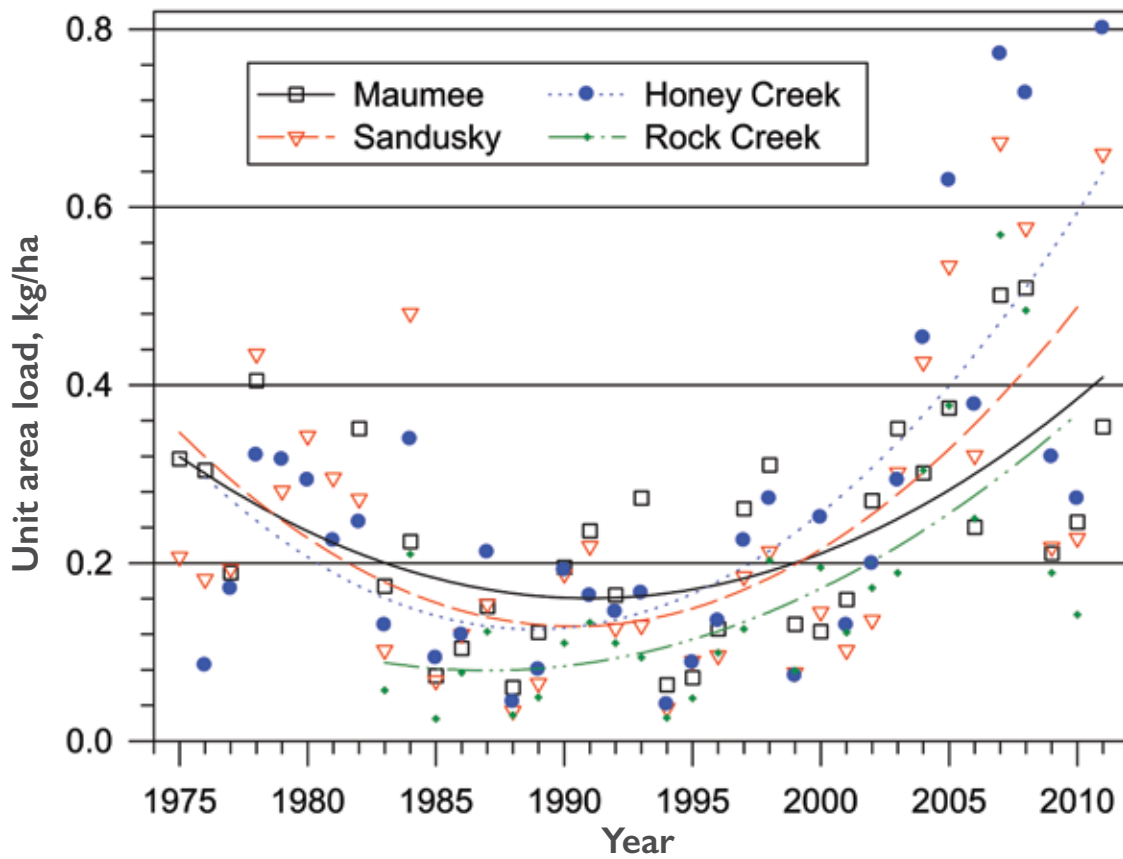
Work remains to further reduce phosphorus discharges from the Detroit plant. A capital improvement program started in 2000 included more than \$1 billion for controlling combined sewer overflows. However, in 2012, the plant still was responsible for the release of more than 29.4 million m³ (about 7.8 billion gallons) of untreated or partially treated sewage into the Detroit River. Moreover, uncertainty remains regarding future improvements, as Detroit's bankruptcy portends potential changes in the governance and funding structure for the Detroit Water and Sewerage Department. The outcome of negotiations between city and suburban leaders may affect planned capital improvements estimated at \$1.2 billion over the next four years.

Dissolved Reactive Phosphorus (DRP)

The Agreement originally focused on TP as the water quality parameter by which Lake Erie eutrophication was to be assessed and managed, and those load targets have generally been met since the 1980s. However, recent research has identified DRP, a form of phosphorus that is highly bioavailable, as a potential issue of concern (Vanderploeg *et al.*, 2009; Richards, 2006). Analysis conducted for the LEEP study of loads from several Lake Erie watersheds revealed that while DRP loads declined in the early 1990s, they have increased since the mid-1990s, in contrast to the relatively stable loads for TP and the fraction of TP known as particulate phosphorus, which is attached to suspended sediment and organic matter (Figure 2-3).

In addition, it was found that *average concentrations* of TP and DRP in the Detroit River are low compared to those measured in other major tributaries. In contrast, the phosphorus concentrations in the rivers draining the agricultural areas of the western basin, particularly the Maumee, are generally much higher and may have a more direct influence on the development of HABs. Nevertheless, the Detroit River represents the largest hydrological loading to Lake Erie and by virtue of its flow, contributes significantly to total phosphorus loading (estimated at 40 to 50%), which may be a significant factor in the annual development of hypoxic conditions in the central basin of the lake (see section 2.3.2).

Figure 2-3
Dissolved Reactive Phosphorus Loads at Four Lake Erie Watersheds



Note: This figure shows unit area loads (kg/ha) for dissolved reactive phosphorus (DRP) for four Lake Erie river systems for the years 1976 to 2011.

Source: NCWQR, Heidelberg University, unpublished data.

Regional-scale Modeling of Nutrients in the Great Lakes Basin

To help address eutrophication problems in the Great Lakes, including the sources of nutrients leading to harmful algal blooms, SPARROW (SPATIally Referenced Regression On Watershed attributes) models were recently developed to simulate phosphorus (P) and nitrogen (N) loading in streams throughout the Great Lakes and Upper Midwest of the United States (Robertson and Saad, 2011). Results from these SPARROW models were used to: estimate P and N loads to each Great Lake from U.S. drainages; rank all United States tributaries with drainage areas greater than 150 km² (57.9 mi²) based on total loads and relative yields; and, determine the relative magnitude of P and N inputs from major sources (atmospheric, point sources, fertilizers, manure, fixation, and forested and urban lands).

Led by the IJC, a binational modeling effort is now underway by the United States and Canada to develop SPARROW models for P and N for the entire Great Lakes Basin, including the complete Lake Erie watershed. These models are being developed using smaller catchments to enable improved spatial descriptions of where and from what sources the P and N originate and calibrated using more accurate loads, including more data from smaller watersheds, than used in previous models. This improved spatial resolution using harmonized hydrographic and geospatial datasets will facilitate comparisons of watershed attributes between the two countries and provide insight into why nutrient loads vary across the Lake Erie watershed. For example, loads from watersheds such as the Maumee and Sandusky rivers in the United States and the Grand and Thames rivers in Canada can be interpreted according to differences in land cover, agricultural practices and wastewater treatment facilities.

A new model that links SPARROW with outputs from water-quantity models, called HydroSPARROW, has been developed. The new model is being used to forecast changes in nutrient loads associated with various future climate and land-use change scenarios projected to occur by about 2050 and 2090.

For more information on the SPARROW model, visit the USGS homepage: water.usgs.gov/nawqa/sparrow/

Internal Loading in Lake Erie

Internal loading of phosphorus is the recycling of external loads that have accumulated and temporarily been stored in lake-bottom sediments in response to in-lake processes. As a result of this internal cycling, lakes can potentially exhibit a slow response to any reduced external loading (Sondergaard *et al.*, 2003). So while internal loading is not “new” phosphorus and cannot be controlled directly, it is important to understand and quantify recycling processes to better anticipate system response times. However, internal loads are not routinely measured and the role of sediment re-suspension from all basins within Lake Erie is not well understood.

There are three types of internal phosphorus cycling in Lake Erie:

- *inter-basin transfers*, involving a transfer of phosphorus entering the western basin (most of the Lake Erie load) to the lake’s central basin;
- *water column recycling*, involving a complex mixture of phosphorus uptake and excretion by algae, bacteria, zooplankton, fish, birds, macro benthos, and micro benthos, as well as death, decay, sedimentation; and,
- *release of phosphorus from sediment* through decomposition of sedimentary organic matter; (particularly under anaerobic conditions) from

iron-rich particulates, and re-suspension of sediment into the water column.

The role of internal loads in delaying responses to external load reductions has been considered, though primarily in small, shallow European lakes (Sondergaard *et al.*, 2003). In these lakes, most reached equilibrium following reduction of phosphorus loads in 10 to 15 years (Jeppesen *et al.*, 2007). It is unknown whether this range of response times can be transferred to Lake Erie, a much larger and more complex system. However, it is important to recognize that in response to the 1972 Agreement, reduced phosphorus loads into Lake Erie decreased western basin phosphorus concentrations from 40µg/L (micrograms per liter) to 20µg/L by the mid-1980s, despite internal recycling.

This information suggests that there could be a delay in the response of the Lake Erie ecosystem to external load reductions of at least several years and possibly longer, due to this internal load cycling. However, in relation to HABs in the west basin, more recent experience, particularly the much smaller spring phosphorus load and bloom in 2012 following the very large load and bloom in 2011, suggests a more rapid response for the blooms than for central basin hypoxia.

2.3 Trends in Effects on the Lake Erie Ecosystem

This section briefly summarizes trends in the effects of phosphorus loading on the Lake Erie ecosystem.

2.3.1 Harmful and Nuisance Algal Blooms

Planktonic Harmful Cyanobacterial Blooms

Beginning in the mid-1990s, increases in highly bio-available DRP loading to Lake Erie have coincided

with a resurgence of planktonic cyanobacterial HABs. Blooms of *Microcystis aeruginosa* and other cyanobacteria have formed annually in the western basin, and now are appearing elsewhere along the coast. In the last decade, the blooms have developed earlier and extended later than in the past. For example, the 2011 Lake Erie bloom was the worst on record (Michalak *et al.*, 2013), and was visible from satellites until mid-October.

Blooms of *Microcystis* have generally been reported from the western basin, but have recently been developing along the shorelines of the central and eastern basins. Potentially toxic species of *Planktothrix* and *Anabaena* have also been observed with increasing frequency (Davis *et al.*, 2012; Saxton *et al.*, 2012). While cyanobacteria are known to produce a number of toxins, microcystins are of particular concern.

Early detection of HAB formation is critical to formation of a proper response. Available detection methods, including remote-sensing, have greatly improved response times in recent years. Molecular methods have tracked historical existence of *Microcystis* dating to the 1970s in Lake Erie, and show that at specific sites the current population is genetically indistinguishable from the historical population (Rinta-Kanto *et al.*, 2009). **This finding suggests that environmental or anthropogenic influences have resulted in a surge in the *Microcystis* population in recent years, rather than an invasion of a distinct population.**

An understanding of the collective effects of these factors will lead to more accurate mathematical modeling and prediction of future HABs. In addition, climate models predict temperature increases that would favour cyanobacterial dominance in freshwaters and may contribute to an extension of annual bloom duration.

Nuisance Algal Blooms in Lake Erie: Benthic Algae

Over the past 10 to 15 years, study of benthic algae in Lake Erie has been largely limited to two species that form annual nuisance blooms: *Cladophora* in the eastern basin; and, more recently, *Lyngbya* in the western basin. These blooms foul recreational beaches, clog municipal and industrial water intakes, impair water quality, and pose potential microbial health risks to wildlife, household pets and humans.

Although the ecology of *Cladophora* is generally well documented in Lake Erie, far less information is available for *Lyngbya*. Recent applications of remote-sensing technology and mobile survey technology have successfully documented spatial patterns in the coverage and attached biomass of *Cladophora* and offer new approaches to expand the spatial scope of future research. Differences in substrate availability and light appear to be major determinants of *Lyngbya* and *Cladophora* abundance in Lake Erie. For example, in the more turbid western basin, *Lyngbya* is often found in turbid shallow water, associated with sand and crushed and live dreissenid mussels (small, freshwater mussels) over a limited depth range (1.5 to 3.5 m [4.9 to 11.5 ft]). *Cladophora*, meanwhile, is found in the more transparent eastern basin attached to dreissenids, rocks and other hard substrate at depths between 0.5 to 10 m (1.6 to 32.8 ft).

The arrival of zebra and quagga mussel populations in Lake Erie likely has contributed to nuisance blooms of *Cladophora* by improving water clarity, supplying nutrients, and providing substrate for filament attachment. This transformation of some stretches of the nearshore zone is consistent with the nearshore shunt hypothesis, which links the trapping of phytoplankton by dreissenid mussels to the proliferation of attached algae (Hecky *et al.*, 2004). The degree of influence of dreissenid mussels on *Lyngbya* is less clear and merits further exploration (Higgins and Vander Zanden, 2010).

The problem of nuisance algal blooms is particularly evident in the nearshore (shoreline and shallow waters adjacent to the shoreline). Nutrient-related problems in the nearshore are worsening, with increasing incidents of algal fouling in many of the Great Lakes including Erie (OMOE, 2013).

It is important to note that much of the information regarding nuisance benthic algal blooms in the Great Lakes in the past (and in more recent years) has been limited to site-specific assessments, supplemented by experimentation and simulation modeling. Researchers now know that there are several important factors influencing the dynamics of benthic algal blooms in nearshore waters of the Great Lakes. Hydrodynamics and circulation of water masses shape the interaction of lake water with land-based runoff and tributary discharges, and strongly influence the nutrient, light, temperature and disturbance regimes in the nearshore. In addition, more is known about the ability of filter-feeding organisms such as dreissenid mussels, to reduce or exacerbate conditions suitable for the growth of benthic algae.

Finally, climate change has the potential to greatly influence these interrelationships, as a result of changes in precipitation and temperature. Such changes likely will significantly alter seasonal growth patterns of algae.

A comprehensive understanding of how these various factors work together to create the conditions associated with nuisance blooms of *Cladophora* and *Lyngbya* is lacking. Addressing this knowledge gap can support the development of sound management activities.

2.3.2 Hypoxia

Hypoxia refers to a condition where the dissolved oxygen content of water is reduced to very low levels. This can occur during the summer months in deeper lake basins, such as the central basin of Lake Erie, where the water column stratifies in layers and the warmer oxygenated waters at the surface are separated from the colder, denser bottom water.

High external nutrient inputs stimulate the production of excessive organic material (algae and other organisms) in the sunlit surface layers, and the subsequent decay of this material in the bottom waters rapidly depletes the supply of oxygen, creating “dead zones,” where dissolved oxygen levels are so low that fish and other aquatic life cannot survive. Hypoxic conditions also lead to the release of phosphorus from sediments, known as internal loading, which may also contribute to the development of algal blooms.

Hypoxia, especially in the Lake Erie’s central basin, is an annual and natural event and one that probably preceded current urban and agricultural development (Delorme, 1982). In fact, the recurrence of seasonal hypoxic events in the central basin subsequent to the nutrient reductions set out in the Agreement suggests that these events are not due solely to human-induced eutrophication (Charlton *et al.*, 1993).

The dissolved oxygen depletion rate and areal extent of hypoxia, however, can be modified by human activities (Rosa and Burns, 1987; Bertram, 1993). For example, owing to excessive phosphorus inputs that stimulated algae production, dissolved oxygen depletion rates during summer increased during the mid-1900s, producing a hypoxic area as large as 11,000 km² (about 4,247 mi²) (Beeton, 1963). During the height of eutrophication, even the shallow western basin of Lake Erie could become hypoxic during windless periods in summer (Hartman, 1972). In fact, by 1963, even a five-day period of hot, calm weather could cause 50% of the western basin to become hypoxic (Hartman, 1972).

Phosphorus abatement programs initiated as part of the 1972 Agreement are credited with contributing to a decline in bottom hypoxia in both western and central Lake Erie through the early 1990s (Charlton *et al.*, 1993). However, since the late 1990s, the extent of bottom hypoxia has increased to levels on par with those observed during the previous era of eutrophication prior to the Agreement (Hawley *et al.*, 2006). The causal mechanisms for this increase are not fully understood, though the shift does coincide with altered precipitation patterns, warmer water

temperatures, increased non-point nutrient inputs and extensive algal blooms.

Climate Change and Hypoxia

Climate change is predicted to influence hypoxia formation in the Lake Erie ecosystem in several ways. Predictions made for other temperate freshwater ecosystems indicate that continued climate change likely will exacerbate the magnitude, duration and frequency of hypoxia (Kling *et al.*, 2003; Ficke *et al.*, 2007; Fang and Stefan, 2009; Jiang *et al.*, 2012). Most directly, warmer future conditions are expected to facilitate a longer stratified period during summer, with earlier establishment of thermal stratification and turnover occurring later in the year. Bottom dissolved oxygen depletion, therefore, will begin earlier and hypoxic conditions are likely to persist over an extended time period (Fang and Stefan, 2009). Reductions in water levels could further exacerbate bottom hypoxia.

While uncertainty surrounding future regional precipitation patterns is greater than the uncertainty about future regional temperatures, it is plausible that precipitation patterns will be characterized by less frequent, but more intense, precipitation events (Kling *et al.*, 2003; Kunkel *et al.*, 1999). Such intense events could lead to higher nutrient runoff from agricultural and urban lands, and, in the absence of dramatic changes in land use, lead to increased overall nutrient loads to Lake Erie. Depending on the timing of runoff, future nutrient loading, coupled with warmer water temperatures, could lead to greater overall phytoplankton production and ultimately exacerbate decomposition and oxygen depletion rates.

Potential changes to future wind patterns have not received the same amount of attention as temperature and precipitation (Kling *et al.*, 2003). By affecting thermal stratification, wind pattern changes also have the potential to alter hypoxia patterns. Specifically, intense wind events could contribute to mass movement of water, including seiches (caused by high sustained winds from one direction that push the water level

up at one end of the lake and make the level drop by a corresponding amount at the opposite end) and the potential influx of hypoxic bottom waters into nearshore zones. As well, strong wind events could facilitate vertical mixing and both delay stratification in the late spring and bring about earlier turnover in the fall, decreasing the period of oxygen depletion. In short, while future wind patterns likely will affect hypoxia patterns, the magnitude (and even direction) of such effects is unclear.

The effects of hypoxia on food webs (particularly invertebrate and fish communities), and how this may be influenced with climate change, are addressed below.

2.3.3 Effects on Fish

Lake Erie fisheries have important ecological, recreational and commercial value. Each species of fish has preferred food choices and temperature ranges, and all depend upon adequate oxygen. In general, the shallow, warm and productive western basin is currently dominated by species that are tolerant of high turbidity and warm temperatures. The eastern basin, the deepest, coldest and least productive, is dominated by deepwater fish, such as lake trout, that prefer cold temperatures, high dissolved oxygen and non-turbid waters. The central basin is dominated by cold water species, including yellow perch and walleye.

Algal blooms in Lake Erie indirectly reduce the integrity of native fish populations through loss of aquatic habitat. When algae die, the decomposition process uses much of the available oxygen dissolved in the water column. This effect is variable in combination with other factors, and is most pronounced in the deeper waters of the central basin where a hypoxic 'dead zone' forms. Additionally, decomposing algae on the lake bottom may play a role in the *Type E* botulism outbreaks that cause significant numbers of deaths of fish-eating birds (Lake Erie Committee, 2003).

As described above, warmer temperatures, lower lake levels and increased frequency of intense precipitation

events all have the potential to enhance phytoplankton blooms, reduce water clarity and exacerbate future hypoxia. Changes in lake temperature may dramatically alter the existing distribution of fish species, even to the loss of cold water species from the lake. Further, organisms that can readily avoid hypoxic regions (through vertical or horizontal migrations) may be forced to occupy inferior habitats, immediately constraining growth.

Such behavioral migrations may alter the overlap, efficiencies, and vulnerabilities of predators and prey, leading to long-term changes to food-web structure and energy flow. Coincident shifts in invertebrate/fish community composition would be expected.

In general, the interactive effects of climate change and nutrient loading are expected to promote a fish community not unlike that of the 1960s and 1970s, which was more tolerant of eutrophic conditions (that is, relatively high concentrations of nutrients). Visual feeding, cold-water and hypoxia-sensitive fish will decline, while species more tolerant to warm water will increase. However, the complex interactions between hypoxia, reduced water clarity, HABs and altered prey base have the potential to directly and indirectly mediate population patterns in ways not yet fully understood.

In addition, the impacts of climate change on lower trophic levels of Lake Erie likely will not be straightforward. Future climatic conditions will undoubtedly interact with nutrient loading and aquatic invasive species in structuring lower trophic level communities. These expected responses would favor eutrophic-tolerant invertebrate taxa. That is, zooplankton and benthic invertebrate taxa likely would increase in abundance if they are able to tolerate relatively warm temperatures, effectively consume cyanobacteria, feed under low light conditions, and utilize a low oxygen zone as a refuge from predation. On their own, expected climate change impacts could lead to invertebrate assemblages trending toward patterns observed during the 1950s and 1960s, at the height of eutrophication, when populations of desirable species sensitive to water quality conditions, such as burrowing may-

flies, were virtually eliminated and the overall diversity of benthos was lower.

2.4 Effects on Human Health and Socio-economic Conditions

Lack of data severely limited efforts to estimate the economic effects of Lake Erie algal blooms throughout the entire lake basin. For example, the LEEP study was unable to quantify impacts related to HABs on coastal property values, commercial fishing, boating, and the tourism industry. As a result, the study chose to limit its analysis of economic costs and benefits to the state of Ohio, which has more recent and available relevant information than other jurisdictions in the Lake Erie Basin. The Ohio data, therefore, can serve as a proxy, providing illustrative order-of-magnitude data on economic costs and benefits that could be expected at the broader regional level.

2.4.1 Human Health

The Agreement places considerable emphasis on preventing human health effects from use of waters of the Great Lakes. Of the five Great Lakes, only Lake Erie has an indicator status of 'fair to poor' for HABs (SOLEC, 2012).

Research on the effects of HABs on human health dates back to the 1930s (IJC, 2014). Cyanobacteria, more commonly known as blue-green algae, produce toxic cyanotoxins. Microcystis is the most common cyanobacteria in the western basin of Lake Erie, and produces the secondary metabolite microcystin. In addition to microcystin-LR (the most toxic of all the microcystin variants), other cyanotoxins found in Lake Erie are on the USEPA's Contaminant Candidate List 3, including *anatoxin-a* and *cylindrospermopsin*.

Individuals swimming, waterskiing, or boating in HABs can be exposed to microcystins. Although the likelihood of people being seriously affected by a *Microcystis* bloom is low, minor skin irritation can occur with contact. As well, gastrointestinal discomfort and,

in very rare but severe cases, acute liver failure can occur if water from a bloom is ingested.

A recent assessment of human health effects from HABs completed for the IJC's Health Professionals Advisory Board (HPAB) found that exposures to cyanotoxins have led to acute animal and human toxicity and acute lethal poisonings in domestic animals and wildlife in many Great Lakes states and Ontario (IJC, 2014). In the Great Lakes basin, only Lake Erie has had documented cases of human illness and animal (dog) deaths.

In cases where HABs appear, municipal water treatment facilities drawing water supplies from Lake Erie may need to carry out additional treatment before the water is safe for human consumption. A 2009 survey of 15 public water systems in Ohio using lake water found that 10 reported having used additional treatments in response to algal bloom events that year (OEPA, 2010). These treatments included the application of powdered activated carbon, chlorine dioxide, and potassium permanganate. Additional control costs totaled \$417,200 for the 10 water utilities, ranging from individual plant costs of \$400 to \$240,000. It is important to note that algal bloom events of 2009 were less severe than in 2011, and as such, these costs can be seen as a conservative estimate.

Public concerns about the impact of HABs on drinking water in Lake Erie were heightened in the summer of 2013. Residents in Carroll Township, OH, were advised not to drink water from their local treatment plant due to high levels of microcystin – the first time a toxin associated with algae led to a plant shutdown in the state. About the same time, water treatment plant operators in Toledo announced they required an additional \$1 million to properly treat microcystin in Lake Erie water supplies. Other water treatment plant operators are incurring additional costs, as well. These events coincided with the IJC's public open houses on the draft LEEP report, and a number of residents raised the issue of HABs and drinking water during the consultations.

Despite the human health threat posed by HABs, there is little guidance provided to drinking water treatment plant operators. In the United States, there are no USEPA standards or mandatory monitoring requirements, and though at least five states have routine state-wide or watershed-based monitoring programs and another four have developed guidance documents to support monitoring at the local level, none of those states are in the Great Lakes basin (IJC, 2014). Health Canada has established a guideline for drinking water of 1.5 parts per billion of microcystin, though there are no routine monitoring requirements in Ontario. The World Health Organization recommends that treated drinking water not exceed more than 1 part per billion of microcystin.

The IJC plans to develop a more complete understanding of Lake Erie HABs and drinking water quality, including an analysis of numeric criteria and monitoring for microcystin in drinking water.

2.4.2 Socio-economic Conditions

Property Values

HABs are known to diminish aesthetic qualities of shoreline and nearshore properties. While there are examples from the literature about how changes in water quality can impact property values, the magnitude of impacts of these blooms on nearby property values is not clear.

However, the LEEP study estimated that between 24,000 and 210,000 properties could be affected by HABs if effects to properties extend between 1.6 and 16 km (1 to 10 mi) inland from the Lake Erie coastline. This estimate, coupled with previous findings from study sites including lakes in Maine, the headwaters of the Mississippi River, and Ontario's Hamilton harborfront, suggests that future research to examine changes in housing values along Lake Erie that can be attributable to the presence of HABs is warranted. Increased property values could represent a large share of the benefits of future efforts to reduce these harmful blooms.

Regional Tourism

The presence of HABs can have immediate economic impacts on a region's tourism industry. Blooms can detract from enjoyment of water-based or near-water activities by spoiling aesthetics or producing unpleasant odors. Public health advisories or site closures issued due to the presence of the blooms can keep visitors from participating in activities and keep prospective visitors from making trips. Foregone or shortened trips translate into losses in tourist spending in the region, which in turn have implications on incomes, employment, and tax revenues.

However, the LEEP study concluded that despite the historically severe algal event in the summer of 2011, Ohio's tourism industry statewide and in the Lake Erie region experienced growth over recent years. This finding suggests that a wide range of factors affects annual tourism expenditures, including employment and general economic conditions and summer weather.

Although available data do not point to an immediate economic impact to the tourism industry caused by HABs, there may still be longer-term or delayed impacts in the future. Tourism supports a substantial amount of regional and statewide employment, as well as contributing to local, state, and federal tax revenues. Therefore, it will be important to continue efforts to better understand the potential effects of such blooms on the tourism industry.

Beach Recreation

Ohio's Lake Erie shoreline provides vast and varied beach recreation choices, with 62 public beaches along its approximately 502 km (312 m) coast (Ohio Department of Health, 2010 and 2011). During the serious outbreak of HABs in 2011, the Ohio Department of Health issued advisories at four beaches in Lake Erie's western basin. The advisories, which recommended against swimming and wading, were issued in late August and extended into October.

Combining an estimate of the per trip benefit of reducing one beach advisory obtained from a previous economic study of Lake Erie beaches (\$3.65), the number of beach trips taken to Maumee Bay State Park (178,500), and the assumed equivalence factor between the HAB-related advisory and a typical advisory, the LEEP study estimated the economic value of damages to beach recreation caused by HABs in 2011 to be approximately \$1.3 million for Maumee Bay State Park.

Recreational Fishing

Lake Erie is considered to have world-class walleye and smallmouth bass fisheries, attracting anglers from across Canada and the United States. In 2011, anglers in Ohio took more than 550,000 fishing trips on Lake Erie by private or charter boat, spending on average more than five hours a trip. Recreational anglers on Lake Erie also support a substantial charter boat industry, which totaled an estimated \$9.9 million in revenue in the state in 2010 (Lucente *et al.*, 2012).

HABs pose a threat to the health of the fishery of Lake Erie in several ways. If these effects on Lake Erie's fishery continue to the extent that fish populations decrease, then sport fishing also could decline, contributing to economic losses across the recreational fishing sector. In addition, if algal toxins affect the safety of consuming fish or if taste and odor issues arise frequently enough among sport-caught fish intended for consumption, then recreational anglers may react by taking fewer trips or by taking trips to sites other than Lake Erie.

Applying an accepted economic value per recreational fishing trip, the LEEP study estimated the economic value of impacts to recreational fishing from the severe 2011 HAB event on Lake Erie at approximately \$2.4 million in Ohio.

Commercial Fishing

The LEEP study did not identify any decline in the value of commercial fishing as a result of the 2011 HABs. Rather, the weight and value of the 2011 harvest were above typical values, particularly compared to harvests in the early 2000s. Any economic impacts to the commercial fishery as a result of the linkages among HABs, hypoxia and fish kills may become evident only over a number of years.







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Yellow Perch swimming in Lake Erie.

Chapter 3

Improving the Health of the Lake Erie Ecosystem

The core objective of the **Lake Erie Ecosystem Priority** (LEEP) undertaken by the International Joint Commission (IJC) is to provide advice to federal, state, provincial and local governments in their development of policy and management approaches to help restore the lake's ecosystem by reducing nutrient loads and resulting algal blooms.

Chapter 3 reviews existing and potential initiatives to address the impacts on the Lake Erie ecosystem from phosphorus loading. The chapter:

- describes modeling efforts to identify new phosphorus loading targets that could be established to reduce the loadings into Lake Erie;
- describes the role that best management practices (BMPs) in urban areas and agricultural operations can play in reducing phosphorus loading; and,
- identifies important gaps in monitoring and research.

The chapter also highlights examples of efforts underway by various governments and organizations to address phosphorus loads in Lake Erie.

3.1 Establishing New Loading Targets

Response curves show relationships between variables and were developed to predict levels of harmful algal blooms (HABs) and hypoxia as a function of phosphorus loading. These load-response curves, in turn, can guide the establishment of new loading targets, as part of a comprehensive management plan to restore the ecological integrity of Lake Erie. Due to the bathymetry of the lake, the outlet of the Detroit River and the relative importance of different watersheds as sources of phosphorus, **the western basin is prone to HABs and the central basin is prone to hypoxia.**

3.1.1 Harmful Algal Blooms in the Western Basin

Recent advances in satellite imagery have been used to quantify the extent and severity of HABs in Lake Erie. Stumpf *et al.* (2012) developed a Cyanobacterial Index (CI) for the years 2002 to 2011 and related it to phosphorus loads. CI and area are linearly related, with a CI of 1.0 being approximately equivalent to 300 km² (116 mi²) of bloom. The CI-TP loading model was calibrated using phosphorus data from Heidelberg University and discharge data from the USGS. Stumpf *et al.* (2012) found that spring discharge and

TP loads from the Maumee River during the March-June period were strongly correlated with the CI.

Spring phosphorus loading from the Maumee River is considered a primary driver of HABs in western Lake Erie as the watershed is the dominant source of non-point nutrient loading to the western basin. It contributes about 5% of the discharge to the western basin, but nearly 50% of the phosphorus loading, making the Maumee River a good surrogate for all western basin non-point sources. The other major source of loading to the western basin is the Detroit River, which also contributes almost 50% of the phosphorus load, but more than 90% of the discharge. Detroit River concentrations are considered too low to make a significant contribution to major cyanobacterial blooms in the western basin of Lake Erie, though loadings from the Detroit River may have a larger influence on central basin hypoxia and the overall trophic status of the lake.

The relationship between the March-June TP load and the CI is exponential (Figure 3-1). Uncertainty around predictions of bloom severity tends to increase with higher loads. Rather than use this statistical model to calculate specific numerical CI values or annual forecasts, bloom categories were devised to capture the variability in observed blooms from 2002 to 2011 (Ohio EPA, 2013a). CI categories are: None/Mild (absence of a bloom or a bloom extent considered acceptable); Moderate; Severe; and Extreme (a category observed in Lake Erie in 2011) (Table 3-1).

Using these categories, severe or extreme blooms have been recorded in four of the 12 years and during another two years, borderline moderate/severe blooms have been recorded. Of the remaining six years, two fall into the moderate category and four fall into the None/Mild category.

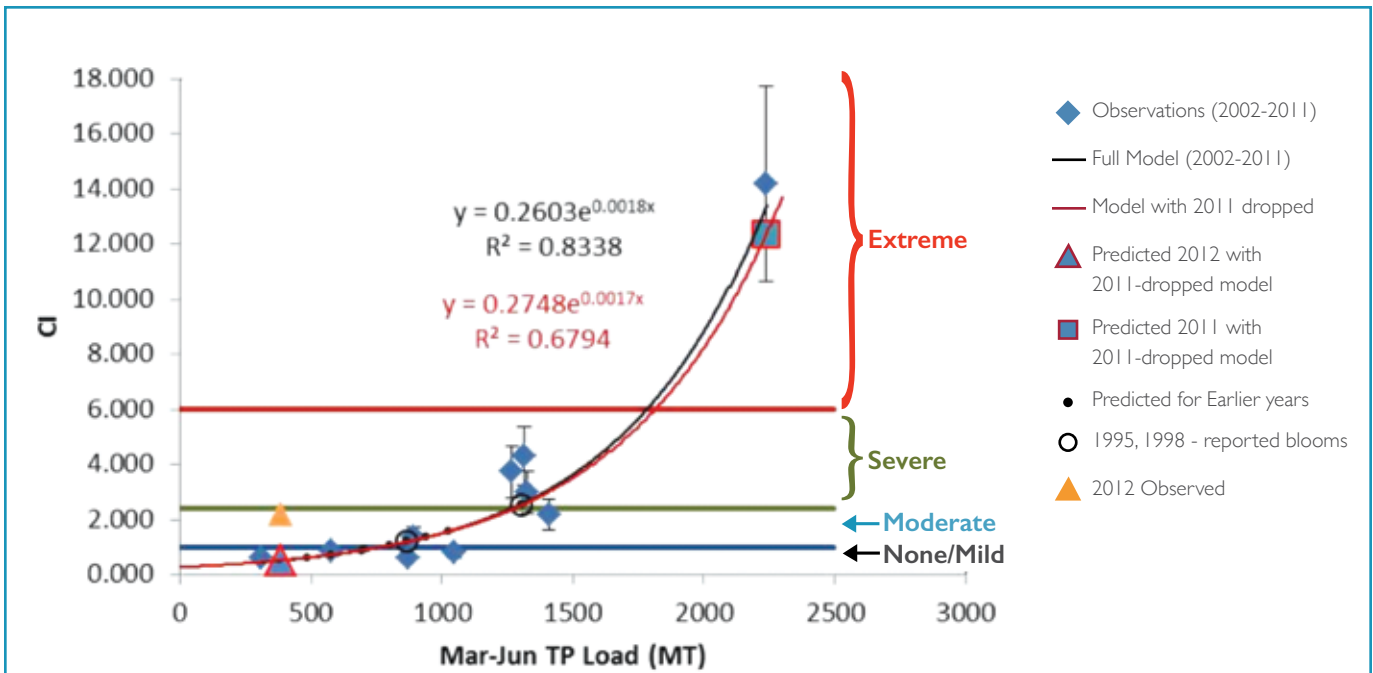


Figure 3-1
Observed and Modeled Response Curve Relationship between Total Phosphorus Load and the Cyanobacterial Index (CI) for the Maumee River

Note: This plot shows the distribution of observed harmful algal blooms in the western basin of Lake Erie, expressed as the Cyanobacterial Index (CI), against total phosphorus (TP) load for the March to June period of each year. CI categories overlay the relationship to show the distribution of blooms observed over the past decade. The diamond and square near the top-right corner of the plot correspond to the year 2011.

Source: modified from Stumpf *et al.* (2012)

To achieve an average annual bloom of None/Mild for western Lake Erie, the provisional TP load target for the Maumee River for the spring (March-June) period is 800 MT (Table 3-1). DRP is considered the most bioavailable fraction of TP and the fraction that triggers and sustains algal blooms. Under the assumption that DRP comprises approximately 20% of TP in western Lake Erie tributaries (Baker 2010; Ohio EPA, 2013a), a provisional DRP target for the spring period can be set at 150 MT. In addition, annual (12-month) load targets for the Maumee River can be estimated with the following conversion factor: Approximately 50% of the annual TP load from the Maumee River enters the western basin during the spring, meaning the provisional annual TP load target for the Maumee River can be estimated at 1,600 MT.

The Maumee River watershed covers about 50% of the western Lake Erie Basin, not including contributing upper Great Lakes watersheds upstream of the outlet of the Detroit River. Other important watersheds that drain into or immediately adjacent to the western basin include the Sandusky, Raisin, Huron, Ottawa-Stony, and Cedar-Portage, among other smaller watersheds. All have approximately the same level of agricultural land use (Han *et al.*, 2012). Therefore, the provisional TP load target for the western basin for the spring period is 1,600 MT and for the entire year is 3,200 MT. The provisional DRP load target for the spring period is 300 MT.

Table 3-1
Proposed Total Phosphorus and Dissolved Reactive Phosphorus Load Targets for the Maumee River Watershed and the Western Lake Erie Basin

Cyano Index (CI)	Bloom Category	Year(s)	Mar-Jun TP load (MT)	Mar-Jun DRP load (MT)	Annual TP load (MT)
Maumee River					
<1	None/Mild	2002, 2005, 2006, 2007, 2012	<800	<150	<1600
1-2.4	Moderate	2003, 2004	800-1,250	150-225	1,600-2,500
2.4-6	Severe	2008, 2009, 2010	1,250-1,750	225-315	2,500-3,500
>6	Extreme	2011	>1,750	>315	>3,500
Western Lake Erie					
<1	None/Mild	2002, 2005, 2006, 2007, 2012	<1,600	<300	<3,200
1-2.4	Moderate	2003, 2004	1,600-2,500	300-450	3,200-5,000
2.4-6	Severe	2008, 2009, 2010	2,500-3,500	450-630	5,000-7,000
>6	Extreme	2011	>3,500	>630	>7,000

Note: Targets are for the March to June period and annually; harmful algal bloom extent is expressed as the Cyanobacterial Index, CI.

Source: Based on Stumpf *et al.*, 2012

For the 2005 to 2011 period of record, the average March-June TP load from the Maumee River was 1,160 MT, the average March-June DRP load was 240 MT, and the average annual TP load was 2,580 MT (Heidelberg University, National Centre for Water Quality Research [NCWQR], Ohio EPA, 2013a). To achieve their respective targets, the March-June TP load reduction factor is 31%, the March-June DRP load reduction factor is 37%, and the annual TP load reduction factor is 38%.

Selection of a baseline period of record for calculation of average annual loads can have a direct influence on load reduction factors. If the 2007 to 2012 period of record from the same Heidelberg University NCWQR database is used to calculate annual loads, the average March-June TP load for the Maumee River is 1,275 MT. Against the same target of 800 MT, the load reduction factor increases to 37%. For the average March-June DRP load (255 MT), the load reduction factor increases to 41% and, for the average annual TP load (2630 MT), the load reduction factor increases marginally to 39%.

In comparing observed average loads against target loads, three additional factors should be taken into consideration. First, the recent trend toward more frequent and larger algal blooms in western Lake Erie means that more recent periods of record yield relatively higher phosphorus load reduction factors than longer periods of record that stretch back into the 1990s. Secondly, if the current trend of DRP displacing particulate phosphorus in TP loads continues, then load reduction factors for DRP will increase. Third, given the scale of the HAB and hypoxia issues in Lake Erie and the degree of nutrient control measures considered necessary to meet these targets, lag times should be anticipated before changes in phosphorus levels and ecological conditions are observed.

Further, the 2012 Agreement includes an interim TP load target for Lake Erie as a whole of 11,000 MT per year. Most of the phosphorus entering Lake Erie does so into the western basin. The response curve relationships reported in Figure 3-1 suggest that the 2012 Agreement's interim target should be revised; on average, annual phosphorus loads of 11,000 MT

will not have the net benefit of reducing the size and severity of HABs in western Lake Erie.

3.1.2 Central Basin Hypoxia

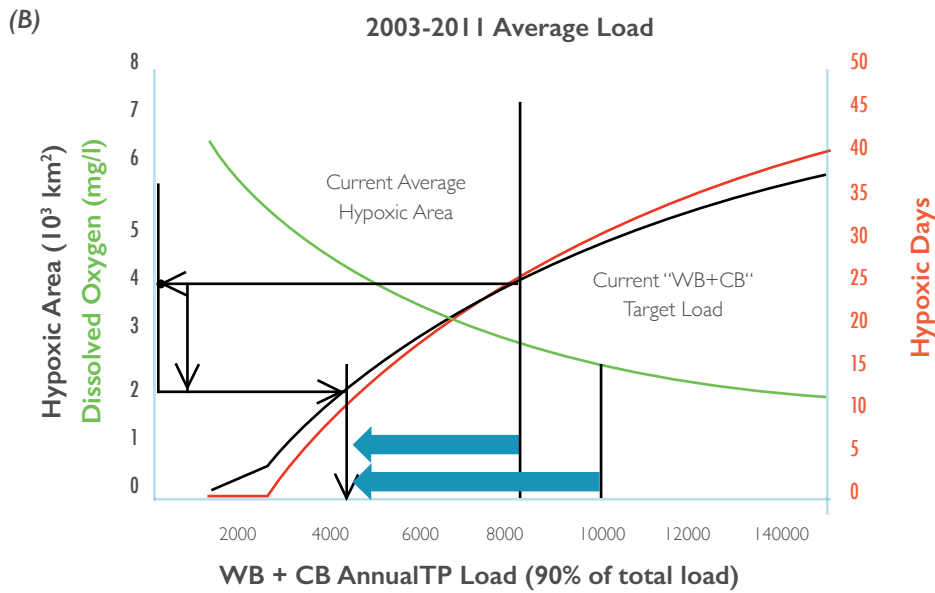
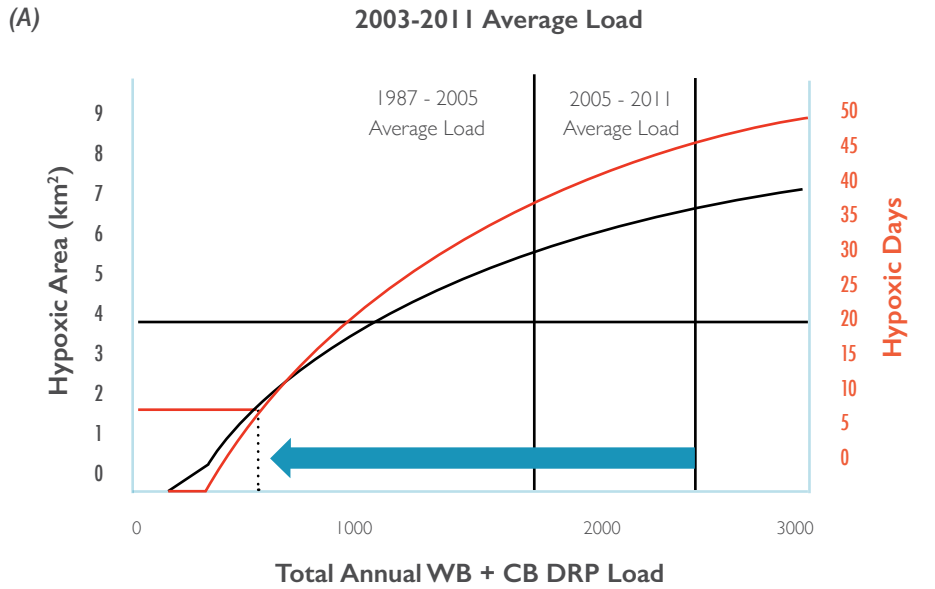
Response curves relating hypoxia to phosphorus loads were developed for the central basin of Lake Erie through application of hydrodynamic and eutrophication models (Rucinski *et al.*, 2010, Rucinski *et al.*, 2014) and geostatistical relationships observed between hypoxic area or hypoxic days and bottom-water dissolved oxygen concentrations (Zhou *et al.*, 2013). In general, higher phosphorus loads are inversely related to dissolved oxygen levels, which, in turn, result in larger hypoxic areas and a greater number of hypoxic days.

Though the Agreement states that an objective for the Great Lakes is to minimize the extent of hypoxic zones associated with excessive phosphorus loading, with particular emphasis on Lake Erie, no targets are specified. Prior to the return of algal blooms in the past decade, the mid-1990s represented a period of time when the extent of hypoxia was considered reasonable, as it coincided with the recovery of several recreational and commercial fisheries (Ludsin *et al.*, 2001). During that period, the hypoxic area was estimated at about 2,000 km² (772 mi²).

For the years 2003 to 2011, the average TP load to the western and central basins of Lake Erie was about 8,000 MT (Figure 3-2). This translates into an average hypoxic area of 4,000 km² (1,544 mi²) and 25 hypoxic days. To decrease the hypoxic area by one-half to 2,000 km² (772 mi²) and to about 10 hypoxic days a year, the target TP load for the western and central basins is 4,300 MT, a 46% reduction from the 2003-2011 observed average load and 56% below the current target.

When expressed as annual DRP load, the target for achieving the same hypoxic area (2,000 km²) and number of hypoxic days (10) is 600 MT. This value is slightly lower than the average estimated for the early 1990s. However, as there has been a significant increase in DRP load over the past two decades, this new level represents a 78% reduction from the 2005-2011 average DRP load.

Figure 3-2
Response Curve Relationships between Phosphorus Loads in the Western Basin (WB) and Central Basin (CB) and Hypoxic Area and Hypoxic Days



Note: (A) Relationship between annual total phosphorus (TP) loads and hypoxic area and the number of hypoxic days; the inverse relationship between TP and dissolved oxygen is also shown. The blue arrows show the amount of TP that needs to be reduced to achieve a desirable level of hypoxia in the CB, relative to the current target load and average observed load for the years 2003 to 2011.

(B) Relationship between annual DRP loads and hypoxic area and the number of hypoxic days. The blue arrow shows how the amount of DRP that needs to be reduced to achieve a desirable level of hypoxia in the CB has increased from the 1987 to 2005 period to 2005 to 2011 period.

Source: Modified from Rucinski *et al.*, 2010

When the ecological issues of HABs and hypoxia are considered together, comparisons can be made between recommended targets between the two sets of response curves. For the long-term elimination of HABs, the March-June TP target recommended by the IJC for the Maumee River is 800 MT, a 31% reduction from 2005-2011 period of record or a 37% reduction from the 2007-2012 period of record. If all western and central basin non-point sources were reduced by the same percentage and applied across the full year, then the resulting annual TP load would be reduced from 8,000 MT to 6,275 MT, which clearly exceeds that estimated for achievement of an average hypoxic area of 2,000 km² (772 mi²), 4,300 MT. Therefore, in setting future targets, it is critical that HAB and hypoxia endpoints are developed separately.

3.1.3 Whole-lake Phosphorus Targets for Lake Erie

Establishment of new phosphorus load and concentration targets is the responsibility of the two national governments. The 2012 Agreement specifies an interim total phosphorus load target for Lake Erie of 11,000 MT per year. It does not specify targets according to the western, central and eastern basins of the lake. However, it does for open water phosphorus concentrations (15 µg/l for the western basin and 10 µg/l for the central and eastern basins). The Agreement indicates that the stated loading targets will stand until updated by the governments of Canada and the United States and that new loading targets for Lake Erie are expected in 2016. Annual time-series data over the past decade show that, coincident with the reoccurrence of HABs, total and particulate phosphorus loads from key United States tributaries have been either levelling off or decreasing, while DRP loads have been increasing. **This suggests that the interim load target for Lake Erie may be obsolete and not reflective of the importance of particular forms of phosphorus.**

Total Maximum Daily Load Process

As noted in the IJC's 16th Biennial Report (Appendix 2), most pollution reduction under the United States Clean Water Act has been accomplished through pollution discharge limits imposed via permits for individual facilities or point sources such as wastewater treatment plants and industrial plants. While effective in reducing a significant proportion of pollution to Great Lakes tributaries and open lakes, a different approach is needed to address most non-point sources, such as pollution runoff from agricultural and other land-based human activities.

In the United States, the Clean Water Act provides a mechanism for addressing both point and non-point sources of pollution for a given water body that does not meet water quality standards for a particular pollutant. These water bodies are deemed "impaired waters." The total maximum daily load (TMDL) process entails calculation of the maximum amount of loading of pollutant(s) of concern that the impaired waterbody can receive and still meet water quality standards for that particular pollutant. The TMDL allocates the load to both point and non-point sources. Following development of a TMDL, implementation should proceed in a way that meets water quality standards and restores impaired waterbodies. States are required to develop TMDLs and may use available regulatory authority in their implementation.

In the case of Chesapeake Bay, a plan with firm pollutant reductions and timelines is taking shape under circumstances not unlike those found in the western Lake Erie Basin. State and federal efforts to remediate the Chesapeake Bay's impaired status date back more than 30 years. The bay is degraded by pollution from both point and non-point sources but, as in the case of Lake Erie's western basin, reduction in polluted runoff from non-point sources has been more difficult to achieve. A number of voluntary cooperative agreements among the six basin states, Washington, DC and the USEPA have not led to progress toward attainment of water quality standards for phosphorus, nitrogen and sediments in the bay. In 2009, President

Obama issued an executive order that, among other things, supported the USEPA's efforts to develop a multi-jurisdictional TMDL for the three pollutants. The agency's authority to do so – and to take action regarding water quality standards and establishment of TMDLs if the states' efforts fall short – was affirmed by the recent ruling of a U.S. District Court. Issued in 2010, USEPA's Chesapeake Bay TMDL establishes waste load allocations of nitrogen representing a 25% reduction from current levels, a 24% reduction of phosphorus, and a 20% reduction of sediments among the Bay jurisdictions. The TMDL sets forth allocations for sectors including non-point sources such as agriculture, on-site septic, and urban sources, and provides target loads for each state and the District of Columbia. States and the District are required to submit watershed implementation plans with specific measures proposed so as to achieve their target loads. Reflecting a 2007 agreement among the jurisdictions, the TMDL requires that all pollution control measures be fully implemented by 2025, with at least 60% of the actions taken by 2017.

An important step in the TMDL process is a state listing of waters as impaired. To date, neither Michigan nor Ohio has listed the open waters of western Lake Erie as impaired by nutrients, despite nutrient-caused algal blooms. The USEPA could call for the states to do so. A related problem is that neither of the two states has developed numeric phosphorus ambient water quality criteria, though Ohio is in the process of developing such statewide criteria. The USEPA could call on Michigan to move forward in developing similar statewide criteria.

3.1.4 Phosphorus Targets in the Context of Adaptive Management

Adaptive management is a planning process that provides a structured, iterative approach for improving actions through long-term monitoring, modeling and assessment. It allows decisions to be reviewed, adjusted and revised as new information and knowledge become available and/or as conditions change. The IJC has embraced adaptive management as an approach for addressing transboundary water issues,

as stated in the Agreement, including extreme water levels in the Great Lakes (International Great Lakes-St. Lawrence River Adaptive Management Task Team, 2013).

The approach also can be applied to the issues of HABs and hypoxia in Lake Erie. Where the Great Lakes-St. Lawrence River adaptive management plan focuses on uncertainty surrounding water level fluctuations as a function of climate change, a Lake Erie adaptive management plan would focus on uncertainty surrounding recommended measures for reducing nutrient loads to the lake and its tributaries. For the issue of HABs in the western basin, the IJC suggests phasing in TP and DRP targets over a nine-year period (2014-2022) by setting transitional targets on a three-year basis to coincide with the triennial cycle and assessment of progress outlined in the 2012 Agreement (Figure 3-3).

3.2 Implementing Best Management Practices (BMPs)⁸

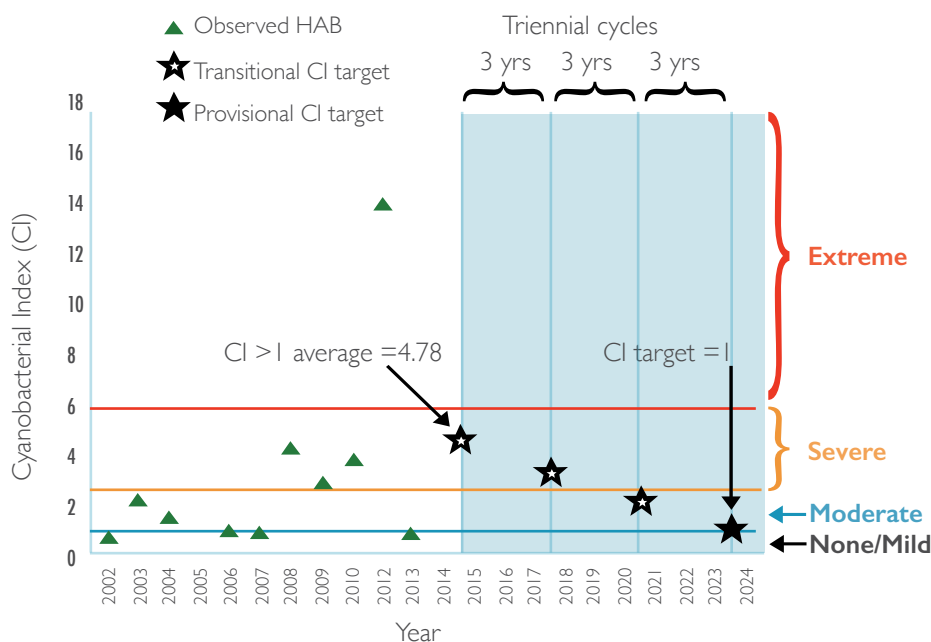
This section presents an overview of BMPs in both agricultural and urban settings that should be considered for implementation within the Lake Erie Basin to reduce phosphorus loads.

BMP is a term used in the United States and Canada to describe a range of practical methods, techniques and other actions that allow individuals or organizations to prevent or reduce the risks of water pollution resulting from activities on the land. BMPs typically evolve over time, as new approaches (for example, based on new information or new technology) are introduced, proven to be effective and adopted.

LEEP undertook a comprehensive review of more than 240 primary sources on the implementation and effectiveness of BMPs in Canada and the United States (McElmurray *et al.*, 2013). The review focused on BMPs that have been evaluated using scientific methods for phosphorus reduction. A secondary focus was to highlight BMPs that have been implemented within the Lake Erie watershed, or more generally, in the Great Lakes region.

⁸ BMPs typically are referred to as beneficial management practices in Canada.

Figure 3-3
Harmful Algal Blooms, Western Lake Erie, as Represented by the Cyanobacterial Index (CI) in an Adaptive Management Context.



Note: Harmful algal blooms (HABs) as represented by the Cyanobacterial Index (CI) are plotted over time from 2002 until 2012 (green triangles). Horizontal lines across the plot correspond to break-points between CI categories that correspond to None/Mild (or acceptable), Moderate, Severe or Extreme blooms. The period from 2014 to 2022 covers the next three triennial cycles of the 2012 Great Lakes Water Quality Agreement, which can serve as three-year transitional targets (open stars) for evaluation of progress between the observed mean annual CI of 4.78 (Severe blooms) and the final CI provisional target (solid star) of 1 (None/Mild blooms).

Source: Observed data from Stumpf et al., (2012) and Ohio EPA (2013a).

3.2.1 BMPs in Agricultural Operations⁹

Agricultural systems have evolved from being net phosphorus sinks, where crop production is phosphorus-limited, to being phosphorus sources, where there is net phosphorus export from most farms (McElmurray *et al.*, 2013). As a result, as noted in Chapter 2, agriculture is the major source of non-point inputs of phosphorus in the Lake Erie Basin.

The basin receives 44% of the TP entering the Great Lakes from agricultural activities, more than any other Great Lake. Commercial fertilizers account for the majority of agriculturally-applied phosphorus in most locations. In Ohio, for example, 84% of phosphorus applied to agricultural land in the Lake Erie Basin is from commercial fertilizers, and 16% is from manure (Ohio EPA, 2013a).

⁹The Ohio Lake Erie Phosphorus Task Force II Final Report (Ohio EPA, 2013a) provides an excellent review and analysis of agricultural practices, nutrient management and phosphorus mitigation. Readers are referred to that document for a thorough review of the issues related to TP and DRP, and policy and management recommendations to achieve phosphorus reduction from agricultural landscapes. Although focused on Ohio, the report has application to other, comparable parts of the Lake Erie Basin.

Livestock production in the basin and elsewhere has trended in recent decades toward a smaller number of larger feedlot operations. Concentrated (or confined) animal feeding operations (CAFOs) are livestock facilities that raise a large number of animals in production barns or confinement pens. These large and concentrated operations generate a large amount of manure, which may runoff to nearby watercourses if not managed properly. It has been estimated that CAFOs account for 60% of the waste from animal feeding operations (Mikalonis, 2013). A review undertaken as part of the LEEP study found that CAFOs are regulated in both Canada and the United States, though in slightly different ways. In Ontario, all CAFOs are regulated under the *Nutrient Management Act*, while in the United States, the operations fall under the *Clean Water Act* (Dupre, 2013).

The control of agricultural phosphorus losses should be directed toward the long-term goal of increasing the efficiency of phosphorus use on farms and therefore, farm profitability. This goal can be achieved through practices that balance inputs and outputs of phosphorus within a watershed and improve the management of soil, manure, and commercial fertilizer at the farm, watershed, or regional scales, while preserving or improving crop and livestock yields.

BMPs in agricultural operations can be grouped according to *source* and *transport*:

- *source* BMPs minimize the potential of phosphorus as pollution at the origin, before it is transported from the soil by water movement; and,
- *transport* BMPs are mostly structures and methods that reduce the transport of phosphorus.

Phosphorus Source BMPs

Table 3-2 summarizes the major BMPs associated with addressing the sources of phosphorus in agricultural operations. Key activities associated with source BMPs include nutrient management, which includes fertilizer and manure management, and animal feed management.

Nutrient management is designed to:

- budget, supply, and conserve nutrients for plant production;
- minimize agricultural non-point source pollution of surface and groundwater resources;
- properly utilize manure or organic by-products as a plant nutrient source;
- protect air quality by reducing odors, nitrogen emissions (ammonia, oxides of nitrogen), and the formation of atmospheric particulates; and,
- maintain or improve the physical, chemical, and biological condition of soil (USDA-NRCS, 2012).

The LEEP study found that nutrient management and related practices in crop-based agriculture (for example, soil and plant tissue testing, fertilizer rates calculation, variable rate application, precision agriculture) were primarily geared toward efficient agronomic output but not necessarily environmental quality. Concern with the latter seems to be more prevalent in animal-based agricultural production and is not well-studied in purely crop-based production agriculture. The effect of fertilizer application rate on phosphorus loss at a farm scale is directly related to application method, the hydrologic soil group, and crop type, among other factors. Nutrient management in combination with tillage and erosion practices may reduce TP loads by more than 80%, but in some cases may increase the loads (Cestti et al., 2003). The efficacy of BMPs improves when multiple BMPs are implemented, rather than a single BMP (Bosch et al., 2013). BMP effectiveness also will vary depending on site conditions.

Manure export from the farm generally is not a viable management option because of hauling costs and off-farm land application options generally are restricted to the nearest neighbors (Sharpley et al., 2006). As a result, in most areas, waste storage, composting, and land applications are the most viable options for manure management.

Table 3-2***BMPs Associated with Phosphorus (P) Sources in Agricultural Operations***

- | |
|--|
| • Balance P inputs with outputs at farm or watershed scale |
| • Minimize P in livestock feed |
| • Test soil and manure to maximize P management |
| • Physically treat manure to separate solids from liquid |
| • Chemically treat manure to reduce P solubility (i.e., alum, fly ash, and water treatment residuals) |
| • Biologically treat manure (i.e., microbial enhancement) |
| • Calibrate fertilizer and manure spreaders |
| • Apply proper application rates of P |
| • Use proper method for P application (i.e., broadcast, plowed in, injected, subsurface placement, or banding) |
| • Carefully time P application to avoid imminent heavy rainfalls |
| • Implement remedial management of excess P areas (spray fields and disposal sites) |
| • Compost or pelletize manures and waste products to provide alternate use |
| • "Mine" P from high-P soils with certain crops and grasses |

(Source: Sharpley *et al.*, 2006)

Reducing Phosphorus Discharges from Greenhouse Operations

In addition to the widespread impacts to water quality associated with fertilizer and manure application to agricultural lands, other agricultural activities can influence Lake Erie water quality. For example, Essex County in southwestern Ontario has the highest concentration of vegetable greenhouses in Canada. When recycled greenhouse irrigation water is no longer useful for growing plants, it must be treated before being discharged to waterways.

In 2011, an Ontario Ministry of Environment study concluded that many Essex County greenhouses discharged wastewater containing high levels of phosphorus to nearby creeks, which in turn discharged to Lake Erie. The province now is working with greenhouse growers to inspect and assess their operations, and ensure measures are taken to reduce phosphorus in their discharges.

Canada –Ontario Environmental Farm Plan (EFP)

The Environmental Farm Plan (EFP) program, begun in Ontario in 1993, is internationally recognized for its success in assisting Ontario farmers to implement more environmentally sustainable practices. To date, more than 35,000 Ontario farmers have participated in the program.

An EFP is a voluntary assessment prepared by farmers to increase their environmental awareness in up to 23 different areas related to their farming operation. Through EFP local workshops, farmers and experts work together to identify each farm's unique environmental strengths and areas of concern. The farmers then set realistic action plans to address the areas of concern, as well as appropriate time tables to improve environmental conditions. Cost-share programs are available to help implement projects and improve environmental weaknesses. Farms with EFPs in Ontario can easily be identified by the '*our farm has an environmental farm plan*' signage.

Source: www.omafra.gov.on.ca/english/environment/efp/efp.htm

Michigan Agriculture Environmental Assurance Program (MAEAP)

All U.S. states offer some form of agricultural outreach and extension services. In Michigan, MAEAP was created in 1998 with the input of a coalition of agricultural, environmental, and conservation groups, who had a common goal: the prevention of agricultural pollution. The program is innovative, proactive, and voluntary to help all farmers in the state of Michigan prevent or minimize the risk of agricultural pollution while keeping their farming operations sustainable. MAEAP is a three-stage process designed to reduce farmers' legal and environmental risks. The program teaches effective land stewardship practices that meet both state and federal regulations, while allowing farmers to identify and prevent agricultural pollution risks from their farming operations. After the requirements are met, the farmer becomes certified and can display MAEAP signage.

To date, 1,400 MAEAP verifications have been completed, more than 10,000 Michigan farmers have started the process, and, an average of 5,000 Michigan farmers attend an educational session each year. MAEAP is credited with reducing soil erosion by more than 272,000 MT (300,000 tons) and phosphorus by more than 227 MT (500,000 pounds) annually. In addition, nearly 4,050 ha (10,000 acres) have been taken out of agricultural production and restored in the form of filter strips and almost 1,900 gullies have been stabilized to protect water quality.

Sources: www.michigan.gov/mdrd/0,4610,7-125-1599-12819--,00.htm osceolalakecd.org/maeap/

The “4R” stewardship framework is a major initiative in nutrient stewardship, jointly promoted by the Fertilizer Institute, the International Plant Nutrition Institute, the International Fertilizer Industry Association, and the Canadian Fertilizer Institute (see text box).

In animal-based agriculture, feed mass balance has become an evolving and important BMP. Animal

farms have decreased in numbers but their capacity has increased in terms of herd size and farm densities. As a result, net nutrient influxes and net nutrient excess occur in most of these farms (Sims et al., 2005). Decreasing phosphorus in feeds is the best method to mitigate phosphorus loss from manure. Manure TP reductions with feed management range from 16 to 33%.

4R Stewardship Framework – Right Source, Right Rate, Right Time and Right Place

Originally developed by the fertilizer industry to increase public confidence in the industry's ability to manage nutrients responsibly, the 4R Stewardship Framework aims to match nutrient supply with crop requirements and minimize nutrient losses from fields (IPNI, 2007). The philosophy of the 4R approach is to base nutrient recommendations and application on scientific principles, including site-specific considerations and adaptive management, with the goal of improved sustainability. The approach provides a framework to achieve cropping system goals that include increased crop yields and therefore farm profitability, and enhanced environmental protection (Ohio EPA, 2013b).

The 4R Stewardship Framework is based on:

1. **Right Fertilizer Source:** matching appropriate fertilizer source and product with soil properties and crop needs. Nutrient interactions should be accounted for and nutrients should be balanced according to crop needs and soil tests. Balanced fertilization is one of the keys to increasing nutrient use efficiency, and therefore reducing excess nutrient loss from the field.
2. **Right Rate:** matching application rates with crop requirements. Excessive fertilizer application may lead to nutrient loss to the environment with no additional gain in crop yield and quality. Soil testing is essential for determining the right application rate, while other BMPs, such as variable rate application and applicator calibration, also can be important.
3. **Right Time:** making the nutrient available when the crops need them. Nutrients are used most efficiently when their availability is synchronized with crop demand. BMPs that influence the timing of nutrient availability include pre-plant or split application timing, controlled release technologies, stabilizers, and inhibitors.
4. **Right Place:** placing and keeping nutrients where the crop can efficiently use them. The method of fertilizer application is critical, and the most appropriate placement method is determined by the crop, cropping systems, and soil properties. Injection or incorporation are most effective at keeping nutrients in place and increasing their uptake by plants, but soil disturbance needs to be balanced with erosion-control BMPs such as conservation tillage, buffer strips, cover crops, and irrigation management. Proper fertilizer placement revolves around applying phosphorus in a manner that maximizes contact, binding, and/or retention of phosphorus with soil to minimize off-site movement.

More information on 4R Nutrient Stewardship can be accessed online, including at www.ipni.net/4R and www.nutrientstewardship.com.

Phosphorus Transport BMPs

Transport BMPs are aimed at erosion control and TP reduction.

Residue and Tillage Management (Conservation Tillage)

Conservation tillage involves management practices that leave at least 30% of the soil surface covered with crop residue following tillage and planting to reduce soil erosion (Galloway *et al.*, 1981). In general, conservation tillage reduces TP loads by as much as 60 to 80% when undertaken in conjunction with other nutrient management practices (Cestti, 2003). However, several studies have evaluated DRP reduction and found a wide range of removal efficiencies (McElmurray *et al.*, 2013). Soil stratification can lead to accumulation of phosphorus at the top of the soil profile, and soil macropores frequently result in the preferential flow of DRP to drain tiles, and then to the receiving environment.

Conservation Cropping

This BMP includes crop rotation, conservation cover and strip cropping. Bosch *et al.* (2009) observed that post-BMP loading of DRP decreased by 74% and nitrate by 73% to 88%.

Conservation Buffers

Conservation buffers are designed to create or improve habitat, and reduce sediment, organic material, nutrients and pesticides in surface runoff and shallow ground water flow. These buffers include contour buffer strips (narrow strips of permanent, herbaceous vegetative cover around landscape contours), riparian forest buffers (areas dominated by trees or shrubs adjacent to and up-slope of watercourses or water bodies) and filter strips or areas of herbaceous vegetation.

However, these features may have limited effectiveness in reducing phosphorus export in the western

basin's agricultural watersheds because buffer effectiveness relies on sheet flow through the feature, whereas in practice buffers often are bypassed by field furrows and concentrated flow outlets. In addition, subsurface drain tiles are common in the west basin's relatively flat, agricultural watersheds with clay soils, and tiles discharge directly to waterways without passing through the buffer (Ohio EPA, 2013b). Forested riparian buffers have been shown to be more effective where they incorporate a wetland function for discharges received from agricultural uplands.

Wetlands Protection and Restoration

Addressing the twin problems of coastal wetland loss and hardened shorelines has potential to benefit water quality in western Lake Erie.

Coastal wetlands and coastal terrestrial systems are important components of Lake Erie ecosystem biodiversity. They also provide ecosystem services such as filtration of polluted non-point source runoff. Both of these systems are highly threatened by coastal development and shoreline alterations, due to the resulting physical alteration of the land-water interface (SOLEC, 2009).

Lake Erie has lost more than 80% of its pre-settlement coastal wetlands, significantly affecting water quality as well as habitat. The 2006 Lake Erie Lake-wide Management Plan observed: “[P]hosphorus can be strictly managed, but unless natural land or habitat is protected and restored, only marginal response will be seen by many components of the ecosystem. It was determined that changes in land use that represent a return towards more natural landforms or that mitigate the impacts of urban, industrial and agricultural land use, are the most significant actions that can be taken to restore the Lake Erie ecosystem.” (LAMP, 2006)

In a study of lakes in the Pacific Northwest, Scheuerell and Schindler (2004) found a negative relationship between TP concentrations and fish aggregations, suggesting that as the number of coastal houses per unit of lake area increases, TP also increases and fish aggregations decrease.

A restorable wetlands assessment for the United States portion of western Lake Erie (not including the Detroit River) prepared for The Nature Conservancy suggests a potential restorable wetland area of 63,841 ha (157,755 acres) – a figure that likely underestimates the true potential, as it does not include any areas currently inundated by the lake (Saarinen *et al.*, unpublished).

Based on data developed by the Great Lakes Coastal Wetland Consortium, there are now about 10,455 ha (25,835 acres) of coastal wetlands in the western basin (including the Detroit River and Ontario). The Nature Conservancy's Lake Erie Basin Conservation Strategy (LEBCS) goal to increase wetland area by 10% suggests a need for 1,046 ha (2,584 acres) of new coastal wetlands in this area by 2030. Given the recent pace of wetland conservation and restoration and the commitment by agencies and organizations at all levels and on both sides of the lake, this goal is feasible, contingent on funding. The cost of achieving this goal in the United States alone is likely to approach \$19 million. However, wetlands provide substantial economic benefits, including, for example, improving water quality by filtering pollutants, storing floodwaters, and serving as fisheries habitat.

Restoring natural land cover and softening shorelines also are key initiatives. Based on an analysis of land cover data from the National Oceanic and Atmospheric Administration Coastal Change Analysis Program and the Ontario Ministry of Natural Resources Land Information Ontario Program, the entire Lake Erie coastal area (within 2 km [1.2 mi] of the lake) falls short of The Nature Conservancy's goal of 40% natural land cover (Pearsall *et al.*, 2012). The western basin is particularly deficient, generally falling well below 30%. The western basin also leads the lake in the amount of artificial shoreline.

Drainage Water Management

Agricultural drainage practices throughout most of the Lake Erie Basin are designed to remove water quickly from the landscape through an elaborate network of subsurface and surface drains. This BMP

manages the discharge water from surface and/or subsurface agricultural drainage systems to avoid impacts on downstream receiving waters. Typically, drainage water management involves the installation of adjustable retention devices to interrupt runoff and drain tile discharges. Drainage and water table management practices address both crop productivity needs, as well as environmental objectives.

A review conducted for the LEEP study found that previous studies have focused only on nitrogen reduction from drain tiles. It noted that this focus reflects conventional wisdom in the past that the majority of phosphorus losses occur as particulate phosphorus attached to sediments transported by surface runoff (McElmurray *et al.*, 2013). The same review found a number of studies that confirmed drain tiles are a source of phosphorus to streams. Additional research on the efficacy of drainage water management in mitigating phosphorus export is needed.

Current and Emerging Technologies

LEEP identified several current and emerging technologies for the reduction of phosphorus loadings from agricultural areas that have received recent research attention and deserve further investigation. These technologies include two-stage ditches (Powell *et al.*, 2007), controlled drainage (Kroger *et al.*, 2011; Nistor and Lowenberg-DeBoer, 2007), hydrologic attenuation, and treatment of tile outlet discharge with, for example, bioreactors and filters (McDowell *et al.*, 2008).

To conclude, LEEP found that measurements of the efficacy of agricultural BMPs are variable and evolving – and that they vary between locations and site conditions. Therefore, additional research is required. However, the need for additional research should not delay the implementation of the numerous BMPs that have been shown to be consistently effective for reducing phosphorus in both its particulate and dissolved forms, including cover crops and residue management (conservation tillage).

Encouraging BMPs on Ohio Farms: Ohio's Healthy Lake Erie Fund

Less than a year after it was implemented, the \$3 million Healthy Lake Erie Fund has enabled farmers to apply agricultural nutrient reduction practices on more than 14,000 ha (35,000 acres) of farmland in the western Lake Erie Basin watershed.

The Healthy Lake Erie Fund is administered by the Ohio Department of Natural Resources (ODNR) in cooperation with local soil and water conservation districts through the Ohio Clean Lakes Initiative. The main goal of the Ohio Clean Lakes Initiative is to reduce HABs in the western Lake Erie Basin by implementing and installing BMPs to reduce nutrient runoff into the lake.

Under the Healthy Lake Erie Fund, farmers have adopted a range of agronomic practices, including cover crops, variable rate fertilizer applications, nutrient incorporation and controlled drainage structures. Participating farmers are required to conduct soil tests to determine the nutrient levels and follow recommendations to determine the appropriate amount of fertilizer to apply to their fields. The ODNR plans to designate some of these farmers as “ambassadors” so they can share their experiences and help expand the adoption of additional practices by other farmers throughout the western Lake Erie Basin and the rest of Ohio.

Source: www2.ohiodnr.com/cleanlakes/healthy-lake-erie-fund

Agricultural Practices and DRP

As noted in Chapter 2, the management of DRP has become an increasingly important issue, due to the large fraction of DRP that is bioavailable. How to best manage DRP is of particular importance in considering BMPs for agricultural practices.

The recurrence of severe algal blooms in Lake Erie since the mid-1990s coincided with an increase in DRP loads. A combination of several factors may have caused the increase in DRP export from agricultural lands (Ohio NRCS, 2012):

- conservation practices (for example, reduced- and no-till cropping systems) implemented since the early 1990s across the basin focused on reducing sediment and TP, but these practices are less useful for controlling DRP;
- farming equipment has become larger and producers now typically broadcast fertilizer onto the

soil surface, rather than banding, where fertilizer is placed adjacent to the crop;

- large-equipment traffic may have caused soil compaction, resulting in decreased infiltration and increased runoff;
- increasingly, fertilizer is applied in the fall instead of spring;
- the application of two years' worth of fertilizer in one year for a corn-corn or corn-soybean crop sequence saves money, time, and labor for the producers but results in higher rates and amounts of fertilizer available for export out of the cropland into the streams; and,
- the maximization of crop yields through fertilizer application and the use of conservation tillage also may have increased soil phosphorus levels, particularly at the soil surface (soil stratification) over a long period of time.

Finally, it is important to note that the effectiveness of BMPs in agricultural operations is likely to be chal-

lenged by a changing climate. For example, recent data indicate that large phosphorus loads – including DRP – are exported into Lake Erie during major storms. Under future climate conditions, such storms likely will become more frequent and more intense. However, current BMPs are targeted primarily to reducing particulate phosphorus, not DRP. Therefore, there will need to be a shift in focus for BMPs in agricultural operations to take into account this climate change effect.

Rural Residential Areas and On-Site Septic Systems

On-site septic systems likely are contributing to phosphorus loadings in the Lake Erie watershed. Maintenance of such systems and replacement of failing systems by homeowners is an element of proper stewardship.

In rural areas and small communities, municipal sewers typically are not available. Instead, homes often discharge wastewater to on-site household sewage systems (commonly known as on-site septic systems) rather than publicly owned sewage treatment plants. Household sewage systems are used in approximately 20% of all homes in the United States and are also widely used in Ontario.

A septic system is comprised of an underground tank, a network of pipes and microscopic organisms to process waste. Waste leaves the septic tank and is discharged into a drainfield for soil treatment. When properly maintained and operated, septic systems remove viruses, bacteria and organic materials from wastewater.

A malfunctioning septic system, by contrast, can result in contaminants leaching into adjacent drains, watercourses and lakes, posing a risk to the environment and human health. If the drainfield is overloaded with too much liquid, it will flood, causing sewage to flow to the surface or create backups in plumbing fixtures and prevent treatment of all wastewater. This generally happens with older or poorly maintained systems. Systems installed in insufficiently porous soils also may fail. Pollutants released to groundwater or surface water from these systems include phosphorus.

Local health districts in the Lake Erie Basin watershed of Ohio that responded to a 2013 information request reported 252,617 septic systems. An estimated 96,339 of these systems were failing, a failure rate of 38.14%. Leading causes of failure included age (53%) and soil limitations (41%). In Ontario, approximately 1 million households rely on septic systems, most of them in the Great Lakes basin. Investigators estimate that 30% of those systems are failing to adequately protect the environment (Ontario Soil and Crop Improvement Association, 1999).

Recognizing the potential significance of this source of phosphorus to Lake Erie, the Ohio Phosphorus Task Force estimated in its 2010 report that septic systems in the Lake Erie Basin watershed of Ohio contributed 88 MT of phosphorus per year to local waterways – a level comparable to the estimated 90.4 MT a year in phosphorus loads from combined sewer overflows in the state (see section 3.2.2).

The task force recommended establishment of statewide minimum standards and rules to provide program continuity across all 88 counties in Ohio. In its November 2013 report, the Ohio Phosphorus Task Force II observed that this recommendation has essentially been adopted through the promulgation of rules.

In Ontario, standards for design, installation and proper maintenance of a septic system are set out in the Ontario Building Code. Under the code, an evaluation is required on every site where a new or replacement septic system is installed. Additionally, to protect drinking water sources, the Ontario Building Code was amended to include the implementation of a mandatory septic system maintenance re-inspection program in designated areas. A “designated area” is where a septic system is, or could be, a significant threat to drinking water based on the vulnerability of wellhead protection areas and intake protection zones.

Following the death of several Ontarians due to the contamination of a municipal drinking water supply with livestock runoff, the Report of the Walkerton Inquiry (Ontario Ministry of Attorney General, 2002)

issued a series of recommendations, including that septic systems should be inspected as a condition for the transfer of a deed. That recommendation has not been enacted to date.

In Michigan, which lacks a statewide sanitary code, local health departments oversee the installation of on-site septic sewage systems. Approvals for wastewater systems serving single- and two-family dwellings fall under the jurisdiction of the sanitary codes of these local health departments. These codes vary considerably in their requirements.

3.2.2 Urban BMPs

Given the significant loading of phosphorus into Lake Erie from urban areas, there is a clear need to evaluate the effectiveness of urban-focused BMPs. Moreover, because there are many diffuse sources of phosphorus within urban areas, the relevant BMPs will need to be highly varied as well, and targeted for implementation in a wide range of urban activities.

Non-Point Source BMPs

The LEEP study reviewed two types of non-point source BMPs in the urban setting:

- alternative behavior/management BMPs (known as non-structural BMPs); and
- structural (or engineered) BMPs.

Alternative Behavior Management BMPs

Educational campaigns focused on changing behavior of urban residents typically result in only modest changes, with some BMPs adopted more readily than others. A common non-structural BMP often considered by communities facing phosphorus related problems in surface waters is reducing phosphorus loads from lawn fertilizers. Loadings are reduced considerably if fertilization is based on soil tests rather than routine practice (Erickson *et al.*, 2005).

Scotts Phosphorus-Free Lawn Fertilizers

In 2006, recognizing the link between nutrient runoff and algal blooms, the Scotts Miracle-Gro Company made a commitment to the Chesapeake Bay area that phosphorus in its lawn foods would be reduced by 50%. In 2011, Scotts expanded this commitment and pledged to remove phosphorus entirely from their Turf-Builder lawn food maintenance products across the United States. In May 2013, Scotts announced that this goal has been achieved for both the United States and Canada. All Scotts lawn maintenance products are now phosphorus-free; this will reduce the amount of nutrient runoff that is able to enter waterways and promote the growth of potentially harmful algae.

Alternatively, composted manure used as a source of slow-release phosphorus reduces TP loadings to urban streams compared to conventional commercial turf-grass sod imported and maintained with inorganic phosphorus fertilizer (Richards *et al.*, 2008). In Ann Arbor, MI, significant reductions in TP and a trend of DRP reduction followed a municipal ordinance limiting the application of lawn fertilizers containing phosphorus (Lehman *et al.*, 2008). In the same city, Dietz *et al.* (2004) found 82% of residents began to leave lawn clippings in place, while only 11% applied fertilizer after soil tests. However, these latter changes were not found to result in a significant change in phosphorus loadings.

Other non-structural changes include better management of leaves and pet waste, street sweeping, and the use of native plants. One study found that nearly three times more phosphorus was released when leaves were cut (for example, when mulched) (Cowen and Lee, 1973).

In another study, pet waste accounted for 84% of phosphorus inputs on a sample of 360 single-family, detached, owner-occupied homes in the Minneapolis-Saint Paul, MN metropolitan area, where state law restricts the use of phosphorus fertilizer (Fissore et al., 2012). In northern Virginia, regular street sweeping was reported to result in 40 to 70% removal of TP (NVPDC and ESI, 1992). Finally, the use of low maintenance plants that are indigenous to the eco-region are expected to reduce the transport of phosphorus through stormwater runoff (Hipp et al., 1993).

Non-Point Source Structural BMPs

Urban structural BMPs consist of a wide spectrum of approaches – ranging from filtration systems to detention, and designed as artificial systems or applied to natural processes.

Traditionally, stormwater infrastructure was designed to mitigate flooding and move water as rapidly as possible to nearby water bodies. More recently, new infrastructure has been designed and some existing infrastructure has been modified to reduce peak flows, sediment loads and turbidity during runoff events. However, both of these objectives ignore other factors such as nutrient loads that play a significant role in water quality impairments (USEPA, 2009). As a result, BMPs are evolving to be more holistic and sustainable with the aim of reducing pollutant loads (Batroney et al., 2010). The following BMPs appear to be promising structural BMPs in urban settings:

- **porous pavements:** TP removal rates of 60 to 71% have been reported through the use of porous pavements, though one study found no evidence of removal (McElmurray et al., 2013);
- **media filters:** subsurface sand filters are reported to remove 43 to 82% TP (Maniquiz et al., 2010; Leisenring et al., 2010);
- **filter strips/bio-swales:** level-spreader-grassed filter strips along highways appear to result in significant reductions (48%) in phosphorus loadings in stormwater runoff (Horner et al., 1994; McElmurray et al., 2013);
- **green roofs:** these can reduce the peak flow generated from urban roof tops; however, they

may contribute more P than they absorb as a result of leaching from material used to construct the green roof. Limited data indicate differences in performance in the short- versus long-term, suggesting a need for more rigorous long-term study and monitoring (Berndtsson, 2010);

- **bio-retention basins:** include rain gardens, filter boxes and all other vegetative basins designed to increase infiltration and evapotranspiration. Removal efficiencies of phosphorus by bio-retention basins are reported to be as high as 97%, depending on the composition of soils used (Carpenter and Hallam, 2010);
- **detention and retention basins:** treatment efficiencies vary considerably, ranging from 20 to 90% removal, depending on their design (City of Austin, 1995);
- **constructed wetlands:** removal efficiencies of constructed wetlands vary widely, ranging from 30 to 70% of TP loads, with some evidence of reduced DRP loads, as well. However, removal in both subsurface flow and open surface wetlands is hampered by low oxygen conditions that can result in the release of previously sequestered phosphorus (Van de Moortel et al., 2009); and,
- **commercial devices:** oil and grit separators have been found to be relatively ineffective (less than 10% removal efficiency) in reducing TP loads. Another type of commercial device, a subterranean concrete detention basin designed to remove settled solids, similar to septic systems, was found to remove approximately 50% (Zhang et al., 2010).

In reviewing the treatment efficiency of these various structural BMPs, the LEEP study reviewed more than 6,000 records from the International Stormwater BMP Database (www.bmpdatabase.org). Based on this review, the study concluded that:

- only 43% of the samples demonstrated phosphorus removal; and,
- bio-retention ponds and wetland basins were the most effective urban BMPs, with about 82% and 75%, respectively, showing some removal.

Milwaukee Leading the Green Infrastructure¹⁰ Movement

The City of Milwaukee, WI, like many cities in the Midwest, lacked the capacity to contain high-flow water events and discharged pollutants directly into its rivers and Lake Michigan. Milwaukee's greatest problem was outdated infrastructure, which combined stormwater with sewage in the sewer systems. The Milwaukee Metropolitan Sewerage District (MMSD) decided to take the initiative to begin investing in infrastructure solutions and urban BMPs. To solve the issues of high-flow events and the combined sewers, a deep tunnel project was undertaken. The Deep Tunnel project is a 31.2 km (19.4 mi) inline stormwater storage system that has reduced the likelihood of overflow events from more than 50 to less than three times per year.

The MMSD also has implemented a number of urban BMPs to help reduce the amount of runoff entering the sewage system. A commitment to reduce runoff by 15% is being achieved through green infrastructure, native plantings, and low-tech devices. The efforts made by the city are consistent with the Leadership in Energy and Environmental Design (LEED) initiative. Milwaukee now is considering making LEED a requirement for all city-funded development projects. A stormwater fee, based on the percentage of on-site impervious surface area, also has been implemented city-wide. The fee can be challenged by the owner if one or more urban BMPs are implemented on the owner's property. The City of Milwaukee now is a leader in green infrastructure. The city's initiative represents a useful case study of the effectiveness of urban BMPs and provides valuable insights into the implementation of these initiatives.

Note: Green infrastructure refers to the use of vegetation, soils, and natural processes to manage water and create healthier urban environments. At the scale of a city or county, green infrastructure typically refers to the patchwork of natural areas that provides habitat, flood protection, cleaner air, and cleaner water. At the scale of a neighborhood or site, green infrastructure typically refers to stormwater management systems that mimic nature by soaking up and storing water.

(source: USEPA website: water.epa.gov/infrastructure/greeninfrastructure/gi_what.cfm)

The review of treatment efficiency also highlighted the importance of understanding the different forms of phosphorus – total and DRP. For example, detention basins, bio-filters and wetland channels were all found to have clearly different removal efficiencies for total versus dissolved phosphorus.

There are limited reliable data available on the cost of structural urban BMPs. In general, the LEEP study found that engineered infiltration basins are the most expensive, while detention basins and infiltration trenches are among the cheapest. However, these cost estimates are based on a small sample size and a diversity of specific BMPs included within broad categories. Moreover, the estimates do not account for size of watersheds and facilities.

Urban Point Sources

Lake Erie receives the largest municipal load of phosphorus of the Great Lakes, though large-scale wastewater treatment plants in the basin have been nearly 100% compliant with their discharge permits since the 1990s.

However, combined sewer overflows allowed under U.S. permits, in which treatment is bypassed during intense rain or snowmelt, deliver about 90.4 MT a year in TP to the lake from Ohio alone (Ohio EPA, 2010). Nineteen combined sewer overflows discharge untreated sewage directly into Lake Erie and 107 others discharge to receiving waters that empty into Lake Erie, including Mill Creek, the Cuyahoga River, Rocky River, and Big Creek in Ohio (Gomberg, 2007).

Partnerships are Critically Important to Protecting Lake Erie

Many organizations and agencies on both sides of the border play an active role in working to protect and improve the health of Lake Erie. Partnerships both across the border and between public and private groups are critical to achieving the goals of reducing phosphorus loads and HABs.

Lake Erie Lakewide Action and Management Plan (LAMP):The LAMP's Binational Nutrient Management Strategy was a strategic response from Canada and the United States that outlines nutrient management actions to reduce excessive phosphorus loading and the eutrophication of Lake Erie. The report establishes nutrient targets for Lake Erie and its basins and provides goals for nutrient management, research and monitoring. The report also provides recommendations for how governments, academia, conservation authorities, non-governmental organizations, community groups, industry, and the general public can help reduce nutrient runoff to Lake Erie.

Lake Erie Waterkeeper:The Lake Erie Waterkeeper acts as an advocate for the health of Lake Erie and its tributaries like the Maumee and Cuyahoga Rivers. The Lake Erie Waterkeeper website provides the opportunity for members of the public to report pollution and algal blooms. It also provides recommendations for simple measures that people can take to reduce the phosphorus runoff from their homes and neighborhoods as well as ideas for urging government officials to improve wastewater management and best management practices.

Conservation Ontario: Conservation Ontario has been a key player in the *Source Water Protection Program* that aims to protect water quality by reducing runoff and erosion. This program helps farmers and landowners recognize when runoff and erosion may be occurring on their land, and provides recommendations for eliminating those problems. Recommendations include riparian area management, such as the establishment of buffer zones and restoring native plant ranges, and nutrient management measures, such as improving manure storage and handling or treating manure.

National Wildlife Federation:The NWF released a report in April 2013, *Taken by Storm: How Heavy Rain is Worsening Algal Blooms in Lake Erie*. This report examines the link between spring rainfall and Lake Erie algal blooms and notes that heavy rains flush farm fertilizers and manure into local waters, which in turn drain into Lake Erie. This causes a build-up of phosphorus in the lake and, ultimately, toxic algal blooms. The report focuses on the Maumee River and provides a number of solutions to: help implement strong conservation practices; restore the natural landscape and wetlands to reduce runoff; and, reduce carbon pollution that causes global warming.

Ecojustice: In its 2013 *Great Lakes Sewage Report Card*, Ecojustice analyzes 12 Ontario municipalities and ranks each one based on how it deals with sewage treatment. This report was then provided to mayors and city councilors in each of the 12 municipalities, along with Ecojustice's recommendations for improving sewage management. These recommendations include prioritizing sewage infrastructure investment, investing in green infrastructure, and reporting whenever inadequately treated sewage is released.

Ducks Unlimited Canada (DUC) and Ducks Unlimited U.S. (DU):DUC and DU work with public and private landowners to restore and retain wetlands. Natural wetlands play a critical role in the filtering out of nutrients like phosphorus before they reach rivers and lakes. By ensuring that wetlands are restored to health and by protecting currently healthy wetlands, DUC and DU hope to reduce the amount of nutrient runoff that reaches Lake Erie, thereby reducing the size and severity of nuisance algal blooms.

Measuring the Performance of Urban BMPs

The LEEP study's analysis indicated that BMP performance can vary dramatically depending on the metric used (Lenhart and Hunt, 2011). Evaluating BMPs based on concentrations alone can be misleading, because performance varies during and between stormwater runoff events. Particularly problematic is the simple percentage removal metric, because it is dependent on the initial concentration of a pollutant (Zhang *et al.*, 2010) and does not account for background water quality, eco-region differentiation, and background, or "irreducible," concentrations. Additionally, it inherently assumes an association between influent (incoming) and effluent pollutant concentrations (McNett *et al.*, 2011).

Regardless of the type of BMP, three main mechanisms are responsible for phosphorus removal in stormwater: bio-uptake; sorption; and precipitation. Ultimately, phosphorus is retained through physical processes, either by attaching to material within BMPs (for example, sorption to wetland plants) or by settling out directly as a precipitate or indirectly while associated with biological material or suspended solids. Of these mechanisms, sorption reactions are the most common mechanism employed by most BMPs. However, because phosphorus partitioning between particulate and dissolved forms can vary widely depending on the amount and type of solids present and can convert rapidly, improving BMP performance "will also likely need to address dissolved P in order to achieve high and/or consistent pollutant removal" (Leisenring *et al.*, 2010). This need for more advanced analysis of phosphorus is a common theme throughout urban and agricultural BMPs.

3.3 Data and Knowledge Gaps

The LEEP study undertook an extensive review of the data and knowledge gaps in the areas of monitoring and research for addressing lake-wide challenges in Lake Erie.

3.3.1 Monitoring

An appropriate targeted monitoring program is an important element of an effective and coordinated management plan for addressing declining water quality, increasing frequency and severity of algal blooms and associated ecosystem impacts. Monitoring data can provide input for the models used to establish new target loads and feedback on the results of management actions.

Status

The LEEP study conducted an inventory of federal, provincial and state government sampling programs in Lake Erie, as well as programs conducted by academic institutions. The analysis identified a wide variety of monitoring efforts, depending on the purpose of the monitoring.

Sampling programs aimed at the open waters of Lake Erie, such as the USEPA Great Lakes National Program Office's monitoring and Environment Canada's Great Lakes Surveillance Program are undertaken on an annual or bi-annual basis. Other programs, including the Lake Erie Index Station Monitoring (near shore tributaries and open water), the United States National Coastal Assessment (nearshore and open water), the Ontario Broad Scale Monitoring Program (inland lakes), and the New York Lake Classification and Inventory Program (inland lakes), operate on a rotational basis every three to five years. These programs are focused on detecting long-term trends. By contrast, the majority of tributary monitoring programs aim to detect nutrient samples on a monthly basis during the ice-free season.

While the long-term annual or monthly monitoring efforts may give a reasonable picture of the status of nutrients in tributaries and Lake Erie over time, they may not fully capture the complexities of nutrient loading, such as those that occur during wet weather events. This limitation may make it more difficult to calculate nutrient loadings in the long run. The LEEP study found that only a few monitoring programs

sample more frequently, on either a bi-weekly, weekly or daily basis. These programs can capture the effects of wet weather events and can be used to calculate nutrient loading more accurately. Heidelberg University, in Tiffin, OH, has a sampling program that samples on a daily basis and three times daily during wet weather events. The USGS recently installed automated tributary monitoring gauges that monitor on a daily basis and include special sampling during storm events. The Great Lakes Intakes Program (Ontario Ministry of Environment) and the Great Lakes Nutrient Initiative (Environment Canada) both sample tributaries and the nearshore on a weekly basis.

These findings highlight the importance of seasonality, frequency and coordination of programs to meet the different needs of program managers, whether they are focused on loading analysis, modeling, long-term trends or unique wet weather events that can cause a rapid influx of nutrients.

In general, there are frequent sampling programs for DRP and TP in all of the major tributaries to Lake Erie. However, many of the monthly programs do not perform specific sampling during wet weather. There are also consistent efforts to assess the nutrient concentrations in Lake Erie on a less frequent basis. However, many smaller tributaries are not monitored on a regular basis.

Most programs monitor for TP as well as DRP, among a wide variety of other water quality parameters, though several programs have indicated that they do not have the capacity to monitor for DRP. Most but not all of the major water quality sampling programs collect flow data or have nearby gauges that collect flow data. Several programs do not have flow gauges directly associated with the phosphorus water quality monitoring.

Key Gaps in Monitoring

Based on the review of current monitoring in Lake Erie, the LEEP study identified a number of important gaps with respect to monitoring. In general, there are limited detailed data on seasonal in-lake ecosystem

dynamics, including nearshore-offshore connections, and on higher spatial-resolution watershed monitoring, with an emphasis on dissolved and particulate forms of phosphorus. Specific gaps include the following:

Detroit River near the Outlet to Lake Erie

Lack of accurate measurements of Detroit River phosphorus loading creates a sizable uncertainty in the phosphorus budget for Lake Erie. Without current information on the hydrology and chemistry of the Detroit River, it is difficult to estimate flow and phosphorus loads to Lake Erie, disentangle upstream sources of phosphorus, and modernize load targets for Lake Erie as a whole and for its western, central and eastern basins. The IJC notes that the deployment of monitoring instruments in the autumn of 2013 in the lower Detroit River by Environment Canada, through consultations with USGS and others, will be helpful in advancing understandings of phosphorus loadings from the river.

Tributary Monitoring and Loading Measurements

There is limited high-frequency monitoring of phosphorus loading to Lake Erie from key sub-basins, other than that carried out by Heidelberg University's National Centre for Water Quality Research. To track changes over targeted timeframes, including during the critical snowmelt period and rainfall events and develop, refine, and calibrate watershed models, it is important to establish robust monitoring networks. For example, loads quantified for reaches of the Maumee and Sandusky rivers can be used to track seasonal variation and changes in the ratio of particulate phosphorus to DRP, and can be interpreted according to watershed attributes, such as agricultural systems and practices. Monitoring initiated through the Great Lakes Nutrient Initiative along the north shore of Lake Erie and in the Thames River will complement existing, more intensive, monitoring efforts in Ontario's Grand River. This kind of information can enable evaluation of the effectiveness of BMPs and facilitate transfers and scaling of edge-of-field results to other basins and at larger spatial scales.

Lake Erie Charter Boat Association and the Ohio EPA Nearshore Monitoring Partnership

In 2011, the Ohio Environmental Protection Agency gained a partner in its water monitoring program in Lake Erie. With the help of the Lake Erie Charter Boat Association, an increased amount of nearshore data is being collected in the western basin of Lake Erie. Prior to this partnership, Ohio EPA staff monitored 13 nearshore water stations monthly, from March through October. The new partnership enables charter boat captains to help monitor water quality related to HABs between Toledo and Sandusky. The cooperative agreement provides researchers with more data on water quality, the effects of improved watershed management practices, and nutrient loading information in the western basin of Lake Erie from tributary streams.

Source: www.epa.state.oh.us/newsbycategory/tabid/5980/vw/1/Itemid/19/ohio-epa,-lake-erie-charter-boat-association-partner-to-monitor-lake-erie.aspx

Wet Weather Monitoring

There is a need to obtain nutrient loading data during wet weather events at a wider range of seasons in all major tributaries. This need will only increase as a changing climate brings the likelihood of more frequent and intense storm events.

Nearshore Monitoring

Current monitoring efforts in Lake Erie's nearshore are limited, particularly at higher resolution time and space scales. This gap inhibits a better understanding of nutrient dynamics in the ecologically important nearshore, and the exchange of water and nutrients between nearshore and offshore areas.

3.3.2 Research

LEEP identified several key gaps in current understanding of critical relationships in the Lake Erie ecosystem. The IJC acknowledges the important role of the binational LAMPs and Coordinated Science and Monitoring Initiative in establishing and accomplishing research priorities, and the facilitation role of the Lake Erie Millennium Network.

Harmful Algal Blooms

To date, most of the research on HABs has addressed single model organisms. There are gaps in understanding the dynamics of entire bloom communities, including the interactions of the different physical, chemical and biological factors that influence freshwater blooms. This broader view could provide a more comprehensive picture of harmful bloom dynamics, and thus support better modeling efforts and lead to innovative management practices in the field.

One important example of the limited understanding of HABs is the potential impacts of the disposal of dredge spoils in the open waters of Lake Erie. The Toledo Navigational Port, located in the shallowest portion of Lake Erie, is dredged on an annual basis to maintain a clear navigational route, with the spoils relocated for disposal farther out in the lake. However, open-lake disposal may contribute to the occurrence of HABs through re-suspension of nutrient-rich sediments that support algal growth. In 2009, the Ohio EPA estimated that sediment dredged from the Toledo navigational channel contained about 1,096 MT (about 1,209 tons) of phosphorus.

Citing, among other factors, the possible link between open-lake disposal and exacerbation of HABs, the Ohio EPA in 2010 declared, “open lake disposal of these huge quantities of dredged sediment in the Western Basin of Lake Erie is not environmentally acceptable to the State of Ohio and needs to be discontinued.” (Ohio EPA, 2010).

In 2013, the United States Army Corps of Engineers, which is responsible for dredging in the basin, undertook a field assessment to help scientists assess the relative contribution of dredged material disposal to algal blooms in the basin. Data are expected to be available by the summer of 2014.

Nuisance Algal Blooms

Much of the information regarding nuisance blooms in the Great Lakes in the past has been limited to site-specific assessments, sometimes supplemented with experimentation and simulation modeling. Lacking is a comprehensive understanding of how various factors, such as the interaction of lake water with land-based runoff and tributary discharges, can be used to predict the conditions associated with nuisance blooms.

Fish and Fisheries

As noted in Chapter 2, HABs, in combination with greater storm intensities and warmer water temperatures in the summer as a result of climate change, can affect Lake Erie fishes both directly (for example, by altering fish reproduction) and indirectly (for example, by altering food web interactions and the use of particular habitats). It will be critically important to better understand how the rich and diverse fish communities of the lake could respond under the warming trends and altered precipitation patterns associated with continued climate change.

BMPs

There are substantial gaps in the understanding of the effectiveness of current and emerging BMPs designed to prevent or reduce the risks of phosphorus loads to the Lake Erie ecosystem. For example, few studies have quantified phosphorus load reductions by urban or agricultural BMPs within the Lake Erie watershed. Reports of BMP effectiveness are variable and often contradictory.

Model Development

There is an important gap with respect to the development of models that can support the development of future target loads for Lake Erie. For example, the response curves in the LEEP study’s assessment of target loads were based on a limited set of models related to algal blooms and a single set of models related to hypoxia. As was the case when the original target loads were established for Lake Erie under the Agreement, it is important to develop, test, and deploy a suite of models to decrease the uncertainty in the forecasts.

Watershed-based models are useful for quantifying sources of phosphorus from Lake Erie watersheds, evaluating BMPs, and forecasting the influence of climate change on phosphorus loads to stream and river networks.

Environment Canada's Great Lakes Nutrient Initiative

Focusing on Lake Erie, Environment Canada's \$16 million Great Lakes Nutrient Initiative is helping address the complex problems of recurrent toxic and nuisance algae, nearshore water quality and ecosystem health in the Great Lakes. The Initiative targets five priority areas:

- establishing current nutrient loadings from selected Canadian tributaries;
- enhancing knowledge of the factors that impact tributary and nearshore water quality, ecosystem health, and algae growth;
- establishing binational lake ecosystem objectives, phosphorus objectives, and phosphorus load reduction targets;
- developing policy options and strategies to meet phosphorus reduction targets; and,
- developing a binational nearshore assessment and management framework.

The Initiative will help Canada to deliver on key commitments under the Canada–United States Great Lakes Water Quality Agreement.

Source: Environment Canada website: www.ec.gc.ca

United States Great Lakes Restoration Initiative

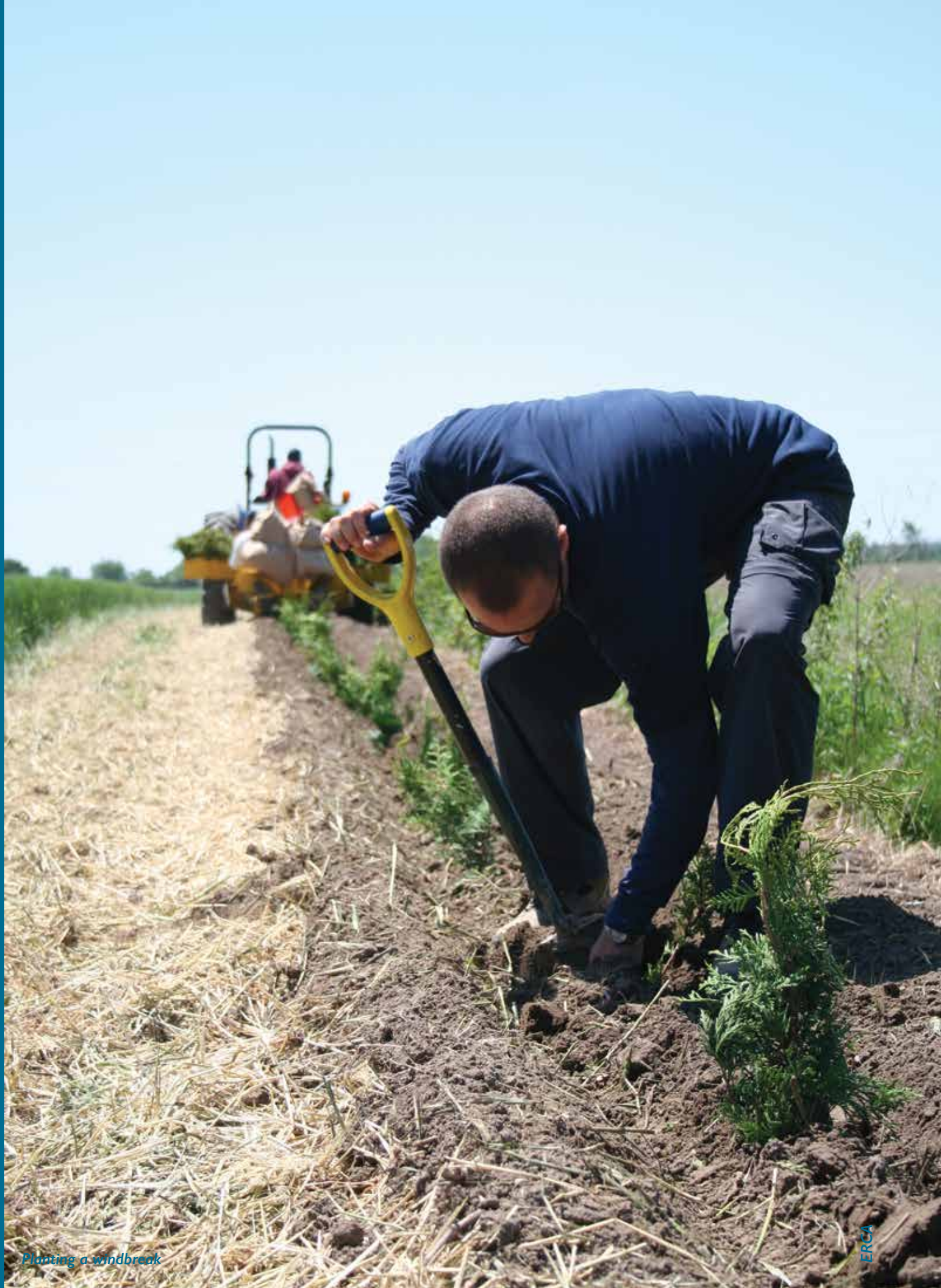
The U.S. government's Great Lakes Restoration Initiative was funded at approximately \$285 million in 2013, bringing the total investment since 2010 to \$1.3 billion. Led by the USEPA, the Initiative has funded numerous projects to restore and protect Lake Erie. One of the Initiative's objectives is to promote nearshore health by protecting watersheds from polluted runoff. Examples of projects designed to reduce nutrient runoff into Lake Erie and tributaries include:

- a \$194,000 project to increase nutrient management plan expertise in the Blanchard River watershed;
- a \$497,000 grant to promote best management practices in the Maumee River Basin; and,
- a \$527,000 grant to promote nutrient reduction in Powell Creek.

(Source: Great Lakes Restoration Initiative website greatlakesrestoration.us/)



Dead Fish, Lake Erie 2011, Western Basin



Planting a windbreak



Green Innovation Great Lakes Program

Example of a green roof at the Village of Medina (NY) wastewater treatment plant.

Chapter 4 Lake Erie Ecosystem Priority: Recommendations

The International Joint Commission (IJC) fully appreciates the formidable challenges ahead in restoring the health of Lake Erie. Harmful algal blooms (HABs) and an expanded hypoxic area developed over a 10- to 15-year period, and remedying these problems will take a comparable amount of time.

History shows, however, that the degradation of Lake Erie by human activities can be reversed by human effort. Fifty years ago, some declared Lake Erie “dead” and suggested that it was beyond remedy. Instead, with the collaboration of governments at all levels, an informed and active citizenry, and strong science underpinning, ambitious goals for Lake Erie’s recovery were established and attained.

The IJC commends the governments of Canada and the United States for renewing their commitment to restore Lake Erie in the 2012 Great Lakes Water Quality Agreement (the Agreement) and for investing in new initiatives that hold promise in furthering understanding and cleanup of the lake. This report is intended to support and inform this work. The IJC is confident that the same government, public and scientific collaboration that reversed the degradation of Lake Erie in the 1970s and 1980s will do so again in the years immediately ahead.

4.1 The Challenge

The **Lake Erie Ecosystem Priority** (LEEP) was initiated by the IJC in 2012 in response to a growing challenge: lake-wide changes in Lake Erie related to problems of nutrient enrichment, compounded by the influence of climate change and aquatic invasive species. As a result of these changes, Lake Erie has experienced a decline in water quality over the past decade, with impacts on ecosystem health, drinking water supplies, recreation and tourism, and property values.

In support of this objective, the IJC has spent much of the past two years developing a better scientific understanding of the causes and controls of phosphorus loading into Lake Erie. This report has presented the major findings of the study in terms of:

- the key factors contributing to changes in the Lake Erie ecosystem, and the important effects of these changes on the Lake Erie ecosystem, human health and socio-economic conditions (Chapter 2); and,
- existing and possible initiatives to address the impacts on the Lake Erie ecosystem from phosphorus loading (Chapter 3).

4.2 Recommendations¹⁰

Responsibility for the development and implementation of plans, programs, policies and related activities to address Lake Erie water quality rests with the governments of the United States and Canada and Ontario and the Lake Erie Basin states (Ohio, Michigan, Indiana, Pennsylvania and New York). The IJC serves in an advisory role to the governments, and offers its recommendations in a spirit of cooperation.

The participation of the province of Ontario and Lake Erie Basin states is essential to realizing improved Lake Erie health. Due to their location around the lake and land use, some states have deeper phosphorus reductions to make than others. For example, while Lake Erie's western and central basins require urgent targeted phosphorus reductions, the states of Pennsylvania and New York State contribute phosphorus loads only to the eastern basin. Efforts to reduce phosphorous inputs into the eastern basin will have little impact on algal bloom and hypoxic conditions occurring upstream. However, reduced phosphorous inputs into the eastern basin will benefit the local environment as well as Lake Ontario, which receives 80% of its flow from Lake Erie.

The IJC's recommendations are grouped into four major categories:

- setting phosphorus reduction targets for Lake Erie;
- reducing phosphorus loading into Lake Erie from agricultural sources and septic systems;
- reducing phosphorus loading into Lake Erie from urban sources; and,
- strengthening monitoring and research in the Lake Erie Basin.

4.2.1 Setting Phosphorus Reduction Targets

New Loading Targets

The 2012 Agreement provides an interim TP concentration substance objective for western Lake Erie of 15 parts per billion, and an interim phosphorus load target for the entire lake of 11,000 MT annually. The governments of Canada and the United States have agreed to develop revised phosphorus concentration objective targets and phosphorus loading targets for Lake Erie within three years of the Agreement's entry into force in 2013. The response curve relationships developed for this report suggest that the interim target of 11,000 MT should be revised; on average, phosphorus loads at this level will not have the net benefit of reducing the size and severity of HABs in western Lake Erie.

The IJC believes that sufficient science exists to propose loading targets for TP and DRP for Lake Erie that will reduce HABs in the western basin and reduce the hypoxic area in the central basin by half. In addition, the IJC believes that phased targets for reduction also should be set for three-year intervals, leading to attainment of the targets within nine years. Such an approach can be established within an adaptive management framework whereby nutrient management policies and practices can be evaluated and prioritized.

Therefore, the IJC recommends that:

- I. **The Governments of the United States and Canada should adopt new targets for maximum acceptable phosphorus loadings in Lake Erie:**
 - to reduce the frequency and severity of harmful algal blooms in the western Lake Erie Basin to an acceptable level (None/Mild blooms), the total phosphorus load target for the Maumee River for the spring (March-June) period should be

¹⁰ Note: Appendix 2 provides an overview of related recommendations on improving Lake Erie water quality from previous reports by the IJC.

established as 800 MT, a 37% reduction from the 2007-2012 average; for dissolved reactive phosphorus, the target for the spring period should be 150 MT, a 41% decrease from the 2007-2012 average; extended over the course of a full year, the total phosphorus target should be 1,600 MT, a 39% decrease from the 2007-2012 average;

- when the rest of the watersheds in the western Lake Erie Basin are included, the total phosphorus load target for the spring should be 1,600 MT and the dissolved reactive phosphorus target should be 300 MT; extended over the course of a full year, the total phosphorus target should be 3,200 MT;
- to decrease the central Lake Erie Basin hypoxic area by 50% to about 2,000 km² (772 mi²) and 10 hypoxic days a year, the target total phosphorus load for the western basin and central basin should be 4,300 MT, a 46% reduction from the 2003-2011 observed average load and 56% below the current target;
- when expressed as annual dissolved reactive phosphorus load, the target for achieving the same hypoxic area (2,000 km²) and number of hypoxic days (10) in the central Lake Erie Basin should be 550 MT. This new level represents a 78% reduction from the 2005-2011 average dissolved reactive phosphorus load; and,
- total phosphorus and dissolved reactive phosphorus targets should be phased in over a nine-year period (2014-2022) by setting transitional targets on a three-year basis to coincide with the triennial cycle and assessment of progress outlined in the 2012 Agreement.

Intergovernmental Cooperation on Targets

The application of the total maximum daily load (TMDL) process under the United States *Clean Air Act* to establish reduction targets in Chesapeake Bay was noted in section 3.1.3. However, Lake Erie presents a key difference, in that Ontario cannot be part of a TMDL process. Without consideration of the On-

tario sources of Lake Erie's phosphorus pollution, a complete picture of the problem and appropriate reduction targets cannot be developed. Therefore, there is a need for cooperation between the two countries on jointly establishing new phosphorus reduction targets.

The governments of Canada, the United States, Ontario and the states that share a common boundary on Lake Erie could apply a public trust framework, a set of important common law legal principles shared by the states, provinces, and both countries. Under these principles – known as the public trust doctrine in the United States and the public right to navigation, fishing, and boating in Canada – the governments could hold Lake Erie as a public trust for their citizens. The public trust framework would provide the governments with an affirmative obligation to assure that the rights of the public with respect to navigation, fishing, swimming, and the water and ecosystem on which these uses depend are protected and not significantly impaired. A public trust framework and principles shared by the common heritage of both countries would be an added measure of protection of the water quality and public uses of Lake Erie and complement the principles and approaches of accountability, anti-degradation, precaution and prevention outlined in Article 2(4) of the 2012 Agreement.

To help attain the IJC's proposed targets, the USEPA could work with the governments of Michigan, Ohio and Indiana to develop a tri-state phosphorus TMDL for the western Lake Erie Basin. The measure would take into account all significant sources of phosphorus loadings, allocate specific reductions of phosphorus according to relative contributions from point and non-point sources, require the submission of state watershed implementation plans to the USEPA, and set timelines for action.

Annex 4 of the 2012 Agreement commits the USEPA and Environment Canada to develop Substance Objectives for Lake Erie phosphorus concentrations and phosphorus loading targets by February 2016, and phosphorus reduction strategies and domestic action plans by February 2018. The IJC recommends that

these processes proceed with greater concurrency so that phosphorus reduction strategies and domestic action plans are completed within six months of confirmation of the Substance Objectives.

Therefore, the IJC recommends that:

2. To establish and implement new targets of phosphorus loadings:

- the governments of the United States and Canada should develop domestic action plans including both regulatory and non-regulatory measures to reduce nutrient pollution of Lake Erie sooner than the 2018 goal set in the 2012 Agreement;
- the governments of Michigan, New York, Ohio, Pennsylvania and Ontario should apply a public trust framework consisting of a set of important common law legal principles shared by both countries, as an added measure of protection for Lake Erie water quality; governments should apply this framework as an added decision-making tool in policies, permitting and other proceedings; and,
- the governments of Michigan and Ohio should, under the United States *Clean Water Act*, list the waters of the western basin of Lake Erie as impaired because of nutrient pollution; this would trigger the development of a tri-state phosphorus total maximum daily load (TMDL) involving those states and Indiana, with U.S. Environmental Protection Agency oversight.

4.2.2 Reducing Phosphorus Loading into Lake Erie from Agricultural Sources and Septic Systems

The IJC concludes that the major sources of phosphorus to Lake Erie now are from non-point sources, especially agricultural operations. Reducing non-point source loads into Lake Erie poses a special challenge. There are many such sources across the area, mostly small in scale and widely distributed. Furthermore, reducing nutrient runoff from these sources requires

changes in practices that until now typically have been voluntary and incentive-based, and may now in some cases need to be enforceable through statute and/or regulation. Even if such practices are adopted, the results might appear only after a number of years and thus it can be difficult to measure their success in the short term.

The IJC also concludes that although TP loads have remained fairly constant since the late 1990s, the dissolved fraction of the total load has increased significantly. There is increasingly clear scientific consensus based on available research and prevailing expert opinion that reducing eutrophication problems in Lake Erie will require significant reductions in phosphorus loadings from agricultural operations.

Federal, state and provincial governments, with sometimes considerable involvement from local agencies and agricultural organizations, have developed a very complex suite of agri-environmental programming in the Great Lakes basin. The governments should accelerate their pursuit of a blend of activities to reduce nutrient loadings to Lake Erie by fully incorporating the following initiatives.

Dissolved Reactive Phosphorus

The LEEP study found that DRP is primarily responsible for driving the problem of HABs in Lake Erie. Yet traditional agricultural BMPs typically are targeted toward particulate phosphorus, which has relatively low bioavailability, though those BMPs have been credited with basin-wide reductions in soil erosion and associated environmental benefits.

As a further complication, the LEEP study confirms that the effectiveness of various BMPs at reducing DRP is poorly understood, though studies currently underway will be instructive. Further, the LEEP study found that the influence of subsurface drainage (i.e., agricultural tiles) is poorly understood and poorly managed in comparison to surface runoff, as is the role of drains in assimilating nutrients from surrounding farmland.

Therefore, the IJC recommends that:

3. The Governments of the United States, Canada, Ontario, Michigan, Indiana, Ohio, Pennsylvania and New York should immediately expand the focus of existing and planned incentive-based agri-environmental programs beyond particulate phosphorus to include an emphasis on best management practices that are most likely to reduce dissolved reactive phosphorus, such as reducing the amount of phosphorus applied to fields, slowing the movement of water to the field drainage system, and detaining flows at field drainage outlets.

Project Targeting

It has long been understood that different locations in the Great Lakes basin have different potential for phosphorus contributions to the lakes based on soil types, climate, gradients, prevailing agricultural practices, and other factors. Research and monitoring have identified the tributaries, and in some cases individual sub-watersheds, that release a disproportionate share of the total amount of DRP entering Lake Erie. The Maumee River in Ohio contributes about 5% of discharge, but nearly 50% of phosphorus loading to the western basin, and should be the primary focus of phosphorus reduction efforts from non-point sources in the Lake Erie Basin. Although project targeting in priority areas is underway – for example, the United States Great Lakes Restoration Initiative Action Plan (USEPA, 2010) and Ohio's Nutrient Reduction Strategy (Ohio EPA, 2013b) identify priority watersheds, as do efforts in Ontario to target the Lake Simcoe watershed – greater emphasis on priority watersheds and sub-watersheds throughout the Lake Erie Basin is required. The need to target phosphorus reduction also responds to the reality that there probably will always be limited resources available to address the sources of agricultural non-point source runoff.

Research conducted in the Maumee River watershed confirms that the spring load (March 1 to June 30) of

phosphorus is highly predictive of subsequent HAB size. Thus, management actions that target the timing of delivery of phosphorus to the lake are also critically important.

Therefore, the IJC recommends that:

4. Future phosphorus management efforts of the Governments of the United States, Canada, Ontario, Michigan, Indiana, Ohio, Pennsylvania and New York should focus on:
 - avoiding agricultural applications of phosphorus in autumn;
 - reducing the load delivered during the spring period (March 1 to June 30); and,
 - those sub-watersheds that are delivering the most phosphorus into the lake, including the Maumee River.

Incentive-based programs

The IJC found that all Lake Erie jurisdictions offer some form of agricultural outreach and extension services, including technical advice and financial assistance for completing agricultural BMPs. As noted above, the effectiveness of BMPs in reducing the impact of phosphorus on Lake Erie would be improved by targeting management actions to the spring runoff period, high delivery potential sub-watersheds, and selecting BMPs that are effective at reducing the dissolved fraction of TP.

Despite the widespread implementation of BMPs, the LEEP study found that the overall proportion of TP loadings to the lake attributable to non-point sources has been increasing, especially from agriculture. Modeling has confirmed that while agricultural BMPs are having some effect in reducing the export of TP from watersheds to the lake, BMPs need to be much more widely implemented to substantially reduce nutrient yields.

Education and awareness-building are essential tools to promote greater adoption of BMPs. Research

suggests that initiatives using a one-on-one interaction and on-farm visits are the most successful at encouraging adoption of specific nutrient management practices. Several jurisdictions have developed special stewardship outreach programs with these features. There is now an opportunity to build on the success of these initiatives throughout the Lake Erie Basin.

Therefore, the IJC recommends that:

5. **The Governments of the United States, Canada, Ontario, Michigan, Indiana, Ohio, Pennsylvania, New York and local agencies should increase the scale and intensity of agricultural best management practices programs that have been shown to reduce phosphorus runoff.**

Lake Erie has lost more than 80% of its pre-settlement coastal wetlands, significantly affecting water quality as well as habitat. These wetlands not only support biodiversity, but also filter pollutants. Opportunities exist for substantial restoration of wetlands in the western Lake Erie Basin and should be pursued as part of a comprehensive plan to reduce algal blooms.

Therefore, the IJC recommends that:

6. **The Governments of the United States, Canada, Ontario, Michigan and Ohio should:**
 - commit to the goal of a 10% increase by 2030 beyond current levels of coastal wetland areas in the western basin of Lake Erie to reduce nutrient pollution and promote biodiversity (an increase of about 1,053 ha or 2,600 acres);
 - allocate adequate funding to support this significant first step in coastal wetland restoration, in concert with non-governmental funders; and,
 - set a science-based goal for protection and restoration of wetlands inland from the Lake Erie coastal zone and develop appropriate strategies to meet the goal.

Regulatory Programs

The IJC’s analysis confirms that for most agricultural operations, the management of nutrients relies primarily on incentive-based programs and influence-based models. The LEEP study found that several decades of this approach have not reduced agricultural non-point sources of nutrients to Lake Erie – TP loads have not declined appreciably in many watercourses draining agricultural areas, and the highly bioavailable dissolved fraction of total loads (DRP) has been steadily increasing. The IJC also found that some regulatory controls are used to supplement traditional incentive- and education-based programming.

Therefore, the IJC recommends that:

7. **The Governments of the United States, Canada, Ontario, Michigan, Indiana, Ohio, Pennsylvania and New York should strengthen and increase the use of regulatory mechanisms of conservation farm planning to reduce nutrient loadings.**

The 4Rs program -- the right fertilizer source, right rate, right time and right place – provides a useful framework for guiding fertilizer application in the Lake Erie Basin and beyond. The 4Rs can be effective in reducing nutrient export from fields, while meeting plant nutrition needs and therefore maximizing crop yields.

The IJC’s analysis determined that there are some good examples of voluntary 4R nutrient stewardship in the Lake Erie watershed. Almost all of the jurisdictions in the Lake Erie watershed have voluntary certification programs, the *4R Nutrient Stewardship Certification Standard* in Indiana, Michigan and Ohio for Lake Erie’s western basin – a voluntary program expected to be launched early in 2014 – noteworthy among them.

However, a review of ongoing efforts to reduce nutrient loadings to Lake Erie revealed that more progress is required to characterize fertilizer use. For example,

Ohio EPA's Ohio Nutrient Reduction Strategy (Ohio EPA, 2013b) describes how current procedures by fertilizer retailers and applicators do not allow for farm-specific tracking of applications. Reporting procedures in other Lake Erie jurisdictions also make tracking fertilizer application difficult. It is also generally accepted throughout the agricultural community that while most farmers routinely sample soil fertility, only a smaller proportion apply fertilizer at variable rates within a field based on those results. Further, agricultural fertilizer application rates are increasing in some locations – for example, trends in the Sandusky River watershed, a predominantly agricultural watershed in Ohio draining to the west basin of Lake Erie, show higher fertilizer application rates in the 1970s and after a reduction in the 1990s, an increase during the past decade (Daloglu *et al.*, 2012). Thus, nutrients frequently are applied at rates that do not reflect site-specific soil fertility needs and exceed the agronomic need of the crops being grown (Carpenter, 2005).

Through a mandatory process that requires training for fertilizer industry actors, well-considered and science-based prescriptions for nutrient amendments at the field level, application practices that minimize runoff, and appropriate record keeping and reporting, nutrient loading to receiving waters can be minimized without compromising crop yields.

Therefore, the IJC recommends that:

- 8. The Governments of the United States, Canada, Ontario, Michigan, Indiana, Ohio, Pennsylvania, and New York should accelerate 4Rs (right source, right rate, right time and right place) outreach/extension programs, and phase in mandatory certification standards for agrology advisors, retailers and applicators to ensure fertilizer is applied based on the 4Rs.**

Regulatory controls should include those that link agricultural program benefits to environmental performance. In both the United States and Canada, crop insurance (also known as production insurance) is a key risk management program available to most pro-

ducers. Crop insurance subsidies are an increasingly large share of U.S. federal agriculture spending, costing approximately \$14 billion in 2012. In Ontario, approximately 2.025 million ha (5 million acres) of farmland are insured through production insurance each year. Both United States and Canadian programs are taxpayer-supported – for example, in Ontario, producers pay 40% of the premium cost while the federal and provincial governments pay the balance of the premium cost and all of the administration costs. The insurance guarantees farmers a certain price for more than 100 crops, including those commonly grown in the Lake Erie Basin. The security provided to farmers by crop insurance is valuable, but there is no linkage between the insurance and environmental stewardship. Without conservation compliance incentives, increased pressure from the marketplace puts marginal areas at risk, resulting, among other things, in tiling and draining of marginal lands, as has happened in the Lake Erie watershed.

Therefore, the IJC recommends that:

- 9. United States and Canadian federal policies should link the cost and availability of crop insurance purchases or premiums to farm conservation planning and implementation of nutrient management practices.**

Regulatory controls include legislated requirements related to the handling and application of nutrients at a national or state/provincial level. Indiana prohibits manure application on frozen ground except in emergencies, while Ontario, New York State, Michigan, Ohio and Pennsylvania allow it under certain conditions. Liquid or semi-liquid manure, which contains phosphorus, cannot easily permeate frozen ground and is much more likely to run off into nearby water bodies, particularly if the region also has snow cover that melts during the winter. The LEEP analysis showed different jurisdictional regulatory responses to application of other sources of phosphorus, including the application of biosolids and fertilizers containing phosphorus on frozen ground and restrictions on manure application rates. It is likely that other areas of difference exist that were not considered as part of the analysis.

Therefore, the IJC recommends that:

10. The Governments of Ontario, Michigan, Indiana, Ohio, Pennsylvania and New York should ban the application of manure, biosolids and commercial fertilizers containing phosphorus from agricultural operations on frozen ground or ground covered by snow for lands that drain to Lake Erie.

The IJC's analysis determined that inadequately maintained and failing on-site septic systems in rural residential areas are contributing to phosphorus loadings in the Lake Erie watershed. Ensuring the maintenance of such systems and the replacement of failing systems by rural homeowners should be an important element of nutrient management. While voluntary efforts of various jurisdictions may prove helpful in reducing the failure rate of household sewage systems, legal requirements to ensure proper maintenance of the systems would provide an added level of protection. For example, some Ontario municipalities have enacted bylaws that require a septic inspection and replacement/upgrade, if necessary, as a condition of land severance. Several local health departments in Michigan have done the same. A requirement that such systems be inspected at regular intervals – for example, every five years – and subject to required maintenance or replacement would further reduce phosphorus loadings to Lake Erie.

Therefore, the IJC recommends that:**11. The Governments of Ontario and Michigan should:**

- enact legislation requiring inspection of septic systems at regular intervals, and at the time of property sale or land severance, to identify and assure upgrade/replacement of failing and potentially failing systems; and,
- expand state/provincial and community education initiatives promoting homeowner awareness of the need for septic system maintenance, including regular pumpout, and upgrade/replacement.

4.2.3 Reducing Phosphorus Loading into Lake Erie from Urban Sources

The LEEP study concluded that there are immediate opportunities to reduce nutrient runoff into Lake Erie from point and non-point sources in urban areas.

Urban Stormwater Management

Urban stormwater can be an important source of nutrients, especially as urbanization increases in the Lake Erie Basin. Construction projects in urban areas can cause significant soil disturbance. Eliminating sod cover and forested areas to make way for development removes water filtration and soil stabilization systems that contribute to the removal of nutrients from stormwater. Stormwater accumulates nutrients from a variety of sources including lawn fertilizers, cleaning agents and other urban residues. Impervious surfaces in urban areas, such as pavement and roofs, are responsible for increases in the volume of stormwater and the distance that it travels to the nearest water-body. Green infrastructure – including green walls, filter strips, rain gardens, bio-swales, engineered wetlands and stormwater ponds, among other measures – can help reduce nutrient runoff in urban stormwater, often at lower cost than traditional “gray infrastructure.” Increased federal, state and provincial incentives, including financial and technical assistance, are needed to support municipalities in the adoption of green infrastructure in the Lake Erie Basin. As an alternative to requirements for more expensive conventional stormwater controls, the Lake Erie Basin states and Ontario also can authorize green infrastructure as a condition of permits or environmental compliance approvals.

Therefore, the IJC recommends that:

12. The Governments of the United States, Canada, Ontario, Indiana, Michigan, New York, Ohio and Pennsylvania should work with municipalities to promote and accelerate the use of green infrastructure (such as filter strips, rain gardens,

bio-swales, and engineered wetlands) in urban stormwater management in the Lake Erie Basin by:

- providing funding, regulatory direction and technical support to municipalities and, where feasible and appropriate as an alternative to more expensive stormwater controls, authorize green infrastructure in United States municipal water discharge permits and Ontario environmental compliance approvals; and,
- encouraging the adoption of local ordinances/by-laws promoting green infrastructure.

Phosphorus Fertilizers for Lawn Care

The application of fertilizer containing phosphorus to turf or gardens in urban areas can contribute to eutrophication, as fertilizer often runs off directly into surface water bodies or into storm sewers that may discharge into the environment without treatment. At the same time, sufficient phosphorus is present in most turf to support healthy lawns without phosphorus fertilizer. In the Great Lakes Basin, Illinois, Indiana, Michigan, Minnesota, New York and Wisconsin have implemented limitations on the use of phosphorus fertilizer and require phosphorus-free fertilizer for most residential lawns. The Minnesota Department of Agriculture reports that since the implementation of lawn fertilizer restrictions in the state, there has been no difficulty for homeowners in finding phosphorus-free fertilizers. The law has substantially reduced phosphorus lawn fertilizer use without increasing consumer costs (Minnesota Department of Agriculture, 2007). Implementing this type of regulation has reduced the amount of phosphorus found in nearby rivers in some cases. This may be significant because similar reductions were not observed in nearby areas that did not have a similar regulation in place (Lehman et al., 2009). Ontario and Quebec do not have province-wide laws that restrict the use of phosphorus for lawn care, though municipalities may pass bylaws that restrict the use of fertilizers in urban settings.

Therefore, the IJC recommends that:

13. The Governments of Ontario, Ohio and Pennsylvania should prohibit the sale and use of phosphorus fertilizers for lawn care, with the exception of the establishment of new lawns during the first growing season or in cases where soil testing indicates a need for phosphorus.

4.2.4 Strengthening Monitoring and Research in the Lake Erie Basin

The LEEP study concluded that an improved understanding of critical relationships in the Lake Erie ecosystem and the ability to model them are core tasks for addressing the complex challenges of nutrient enrichment and the associated environmental and socio-economic impacts. Strengthened monitoring and research are needed to support management initiatives, evaluate the effectiveness of BMPs, and develop models used in establishing new target loads for phosphorus and other nutrients.

Therefore, the IJC recommends that:

14. The Governments of the United States and Canada should commit sustained funding to enhance and maintain monitoring networks in the Lake Erie Basin, focusing on:
 - tributaries throughout the Lake Erie Basin, including key sub-basins and wet weather events to capture seasonal differences from a wider range of basin tributaries;
 - dissolved reactive phosphorus which, in addition to total phosphorus and other parameters, will need to be regularly monitored at all appropriate sites;
 - establishment of water quality monitoring stations to quantify the nutrient dynamics of Lake Huron, the St. Clair River and Lake St. Clair;
 - establishment of a continuous, long-term water quality monitoring system at the outlet of the

Detroit River that measures critical nutrient parameters; and

- an evaluation of the cumulative effectiveness of urban and rural best management practices.

15. The Governments of the United States and Canada should support research to strengthen understanding of:

- the dynamics of harmful algal blooms through a comprehensive limnological approach to studying entire bloom communities;
- how open-lake disposal of dredged sediments from the Toledo navigational channel affects phosphorus loadings in Lake Erie;
- environmentally sustainable methods of sediment disposal;
- how various factors, such as the interaction of lake water with land-based runoff and tributary discharges, can be used to predict the conditions associated with nuisance blooms under current and future climate change scenarios;
- how Lake Erie's diverse and productive fish communities could respond under the warming trends and altered precipitation patterns associated with continued climate change; and,
- the economic effects of Lake Erie algal blooms throughout the entire lake basin.

16. The Governments of the United States and Canada and organizations involved in lake management should improve data management through greater coordination and sharing.

4.3 Next Steps

Through the analyses undertaken during the preparation of the LEEP report and input received through public consultations, several important issues arose that could not be adequately addressed in this report. As a result, the following issues will be further investigated during the remainder of the IJC's Triennial Cycle (2012-2015), and may be the subject of future reports and/or advice to the governments of Canada and the United States:

- developing a more complete understanding of:
 - the economic impacts of Lake Erie eutrophication and the economic benefits of addressing the nutrient threat, building on the LEEP's preliminary economic analysis; and,
 - the costs and benefits to agriculture of nutrient pollution reduction initiatives;
- strengthening the application of water quality models in addressing excessive nutrient loading in Lake Erie and its watershed to support the development of water resource and nutrient management strategies; and,
- developing a more complete understanding of Lake Erie HABs and drinking water quality, including an examination of numeric criteria and monitoring for cyanotoxins in drinking water; building on the Health Professionals Advisory Board (HPAB) report on human health and HABs (IJC, 2014).



APPENDICES

1. Acknowledgements

The International Joint Commission (IJC) acknowledges and expresses its sincere appreciation for the contributions of the many individuals in Canada and the United States who contributed to the planning, research, analysis and report preparation of the **Lake Erie Ecosystem Priority** (LEEP). Dozens of scientists, engineers, planners and technical experts drawn from a wide range of disciplines and from governments and academia have worked together in a true spirit of cooperation to address the critical challenges facing Lake Erie's ecosystem.

The IJC also acknowledges and thanks the many members of the public who participated in the LEEP public outreach events in 2012 and 2013 and who provided valuable comments on Lake Erie's challenges and possible actions to address those challenges.

The following is a list of the individuals who directed participated in the LEEP.

LEEP Leadership and Management

The IJC gratefully acknowledges the work of the LEEP project team, which was responsible for the overall planning and management of the research, analysis and report preparation:

- Raj Bejankiwar, Great Lakes Regional Office, Windsor, ON (Lead);
- Glenn Benoy, Canadian Section, Ottawa, ON;
- Matthew Child, Great Lakes Regional Office, Windsor, ON;
- Dave Dempsey, United States Section, Washington, DC; and,
- John Nevin, Great Lakes Regional Office, Windsor, ON.

Advisory Boards and Technical Work Groups

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- the Great Lakes Science Advisory Board, co-chaired by: William Bowerman, University of Maryland; and William Taylor, University of Waterloo;
- the Great Lakes Water Quality Board, co-chaired by Susan Hedman (U.S. Environmental Protection Agency) and Michael Goffin (Environment Canada); and,
- the Council of Great Lakes Research Managers, co-chaired by Norm Granneman (U.S. Geological Survey) and John Lawrence (Environment Canada).

Taking Action on Lake Erie (TAcLE)

The IJC expresses its sincere appreciation for the work of the Great Lakes Science Advisory Board's *Taking Action on Lake Erie* (TAcLE) work group, which undertook extensive research and analysis of the key research questions and prepared papers summarizing findings and conclusions. The group was composed of board members and experts drawn from governments and academia.

Members of the work group were:

- George Arhonditsis, University of Toronto*
- Nate Bosch, Grace College
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- Sue Watson, Environment Canada*
- Steve Wilhelm, University of Tennessee
- Weitao Zhang, University of Toronto.

* Denotes that the individual also was a participant in the 2013 LEEP Science Synthesis Workshop, below.

Lake Erie Ecosystem Priority (LEEP) Science Synthesis Workshop

The IJC also thanks the researchers who attended the LEEP Science Synthesis Workshop in Windsor, ON, in February 2013. The scientific work that was presented and the lively debate and discussion that followed ensured that this report reflected a diversity of views from a variety of disciplines.

Workshop participants (in addition to IJC staff who attended) were:

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- William Bowerman, University of Maryland
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- Jan Ciborowski, University of Windsor
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Report Production

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- *Technical Editor/Writer*: Tom Shillington, Ottawa, ON; and,
- *Report Design and Production*: Paul Santos, Provisional RGD, Leamington, ON.

2. Related Recommendations from Previous Reports by the International Joint Commission

Under the terms of the previous Great Lakes Water Quality Agreement, the International Joint Commission (IJC) issued biennial reports between 1987 and 2013 assessing the progress of the Parties in achieving the general and specific objectives of the Agreement. Moving forward, the IJC will be issuing triennial assessments of progress, as called for in the 2012 Agreement.

The last two biennial reports included consideration of issues related to LEEP – the *15th Biennial Report* (IJC, 2011) included a section on eutrophication, while the *16th Biennial Report* (IJC, 2013) included a section on phosphorus loadings.

In the *15th Biennial Report*, the IJC recommended that the Parties:

- develop new or improved models to improve estimates of phosphorus loadings to the Great Lakes from tributaries and other sources and use the results to establish phosphorus concentration targets for nearshore and offshore waters of the Great Lakes;
- issue a reference to the IJC for a binational scientific investigation into the causes of the resurgence of nuisance and harmful algal growths in the Great Lakes from land use activities and to test causal hypotheses of the linkages between land use and algal problems and associated ecosystem changes in the Great Lakes;
- institute “no regrets” actions – measures that would be justified under all plausible future scenarios –using adaptive management to better retain nutrients and sediment on the land, especially in watersheds with high phosphorus loadings; and,
- promote the implementation of successful “no regrets” management actions by developing, maintaining, and sharing an inventory of effective techniques and programs.

In the *16th Biennial Report*, the IJC recommended that:

- federal, state, and provincial governments should continue to develop and implement best or beneficial management practices to reduce DRP runoff from agricultural lands and to develop and enforce measures to decrease loadings in high-risk watersheds;
- governments should support and encourage farmers to be aware of recommended phosphorus levels for the crops they are growing, to test soil regularly, and to apply fertilizer or manure to soil only when phosphorus is needed;
- governments should support and encourage development and use of related technologies such as using manure digesters and transporting manure to areas needing fertilizer;
- governments should develop improved models to more accurately estimate phosphorus loadings to western Lake Erie and to other basins experiencing problems associated with excess phosphorus;
- governments should collaborate to develop, maintain and share an inventory of effective management actions that are used to better retain nutrients and sediments on the land, especially in watersheds yielding high phosphorus loadings; examples of such management actions include: nutrient-use planning for croplands and livestock operations; implementing outreach to waterfront residents on better construction and maintenance of septic systems; and, establishing requirements that septic systems be inspected at time of house sale and upgraded when necessary; and,
- the states of Ohio, Michigan and Wisconsin should work with the USEPA to complete phosphorus TMDLs for the respective water bodies of western Lake Erie, Saginaw Bay and Green Bay.

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4. Glossary

ADAPTIVE MANAGEMENT -- A planning process that can provide a structured, iterative approach for improving actions through long-term monitoring, modeling and assessment. Through adaptive management, decisions can be reviewed, adjusted and revised as new information and knowledge becomes available or as conditions change.

ALGAE – Aquatic organisms that survive through photosynthesis; they can range in size from microscopic organisms to large seaweed and giant kelp.

ALGAL BLOOMS – An excessive and relatively rapid growth of algae on or near the surface of water. It can occur naturally as the result of a change in water temperature and current or as a result of an excess of nutrients in the water.

BASIN – All land and water within the confines of a drainage basin.

BEST MANAGEMENT PRACTICES (BMP) – A term used to describe a range of practical methods, techniques and other actions that allow individuals or organizations to prevent or reduce the risks of water pollution resulting from their activities. Best practices typically evolve over time, as new approaches are introduced, proven to be effective and adopted. Also known as beneficial management practices.

BOUNDARY WATERS TREATY OF 1909 – The agreement between the United States and Canada that established principles and mechanisms for the resolution of disputes related to boundary waters shared by the two countries. The International Joint Commission was created as a result of this treaty.

CLIMATE CHANGE – A change of climate that is attributed directly or indirectly to human activity, that alters the composition of the global atmosphere, and which is in addition to natural climate variability observed over comparable time periods.

DISSOLVED REACTIVE PHOSPHORUS (DRP) – The fraction of phosphorus that is dissolved in the water column and generally available to support algal growth.

EUTROPHICATION – The process by which a body of water becomes rich in dissolved nutrients, such as phosphorus, thereby encouraging the growth and decomposition of oxygen-depleting plant life and resulting in harm to other organisms; also known as nutrient enrichment.

EXTERNAL LOADING – Runoff of a pollutant from various point sources and non-point sources in the watershed, from upstream lakes and rivers, and from the atmosphere.

GREAT LAKES WATER QUALITY AGREEMENT (THE AGREEMENT) – First signed in 1972, the Agreement expresses the commitment of Canada and the United States to restore and maintain the chemical, physical and biological integrity of the Great Lakes basin ecosystem.

GREEN INFRASTRUCTURE – Green infrastructure refers to the use of vegetation, soils, and natural processes to manage water and create healthier urban environments. At the scale of a city or county, green infrastructure typically refers to the patchwork of natural areas that provides habitat, flood protection, cleaner air, and cleaner water. At the

scale of a neighborhood or site, green infrastructure typically refers to stormwater management systems that mimic nature by soaking up and storing water.

HARMFUL ALGAL BLOOM (HAB) – Harmful algal blooms (HABs) result from the proliferation of blue-green algae (including cyanobacteria) in environmentally stressed systems, where conditions favor opportunistic growth of one or more noxious species, which displace more benign ones. The blooms are considered harmful because excessive growth can harm ecosystems and produce poisons (or toxins) that can cause illness in humans, domestic pets and wildlife.

“HOT SPOT” – Locations within a lake’s watershed that contribute a disproportionate share of the total amount of DRP entering the lake.

HYPOXIA – A condition where excessive nutrients contribute to algal growth and subsequently high oxygen consumption during decomposition of the algae. This process creates “dead zones”, typically near the lake bottom, where dissolved oxygen levels are so low that fish and other aquatic life cannot survive.

INTERNAL LOADING – Transport of a pollutant from sources within the lake, such as from bottom sediments.

INTERNATIONAL JOINT COMMISSION (IJC) – International independent agency formed in 1909 by the United States and Canada under the Boundary Waters Treaty to prevent and resolve boundary waters disputes between the two countries. The IJC makes decisions on applications for projects such as dams in boundary waters, issues Orders of Approval and regulates the operations of many of those projects. It also has a permanent reference under the Great Lakes Water Quality Agreement to help the two national governments restore and maintain the chemical, physical, and biological integrity of those waters.

LOADING – Entry of a pollutant, such as phosphorus, into a water body.

NEARSHORE – The Lake Erie LAMP divides the nearshore into two areas; coastal margin and nearshore open-water. Coastal margin is defined as the shoreline, water column and substrate in embayments with water depths of 3 meters or less. The nearshore open-water is defined as the water column and substrate with water depths between 3 and 15 meters. Thus, the nearshore is the zone where water depth is less than 15 meters.

NON-POINT SOURCES – Sources of pollutants associated with many diffuse locations and origins, typically transported by rainfall and snowmelt runoff over land; for example, excess fertilizers, herbicides and insecticides from agricultural lands and residential areas.

NUTRIENT – A food, or any nourishing substance assimilated by an organism, and required for growth, repair, and normal metabolism. For example, phosphorus and nitrogen are nutrients for algae.

PARTICULATE PHOSPHORUS (PP) -- The fraction of phosphorus that is attached to suspended sediment and organic matter.

PHOSPHORUS – An element used in a wide range of agricultural, industrial and domestic products; the key nutrient limiting the amount of phytoplankton and attached algae in Lake Erie.

POINT SOURCES – Sources of pollutants, such as phosphorus, associated with a specific location; for example, an industrial or sewage treatment plant.

TOTAL PHOSPHORUS (TP) – Refers to all forms of phosphorus in a given volume of water, including particulate and dissolved forms.

5. Metric System – United States Customary System Units

(with abbreviations)

Length

1 meter (m) = 3.2808 feet (ft)

1 ft = 0.3048 m

1 kilometer (km) = 0.6214 mile (mi)

1 mi = 1.6093 km

Area

1 square kilometer (km²) = 0.3861 square mile (mi²)

1 mi² = 2.59 km²

1 hectare (ha) = 2.47 acres

1 acre = 0.405 ha

Weight

1 metric tonne (MT) = 1.1 short tons (2,200 pounds)



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